ARES

Astromaterials Research & Exploration Science

BI-ANNUAL REPORT 2002-2003

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Office of Astromaterials Research and Exploration Science

Steven A. Hawley, Ph.D. Associate Director, ARES
http://ares.jsc.nasa.gov/

The Office of Astromaterials Research and Exploration Science (ARES) performs the physical science research at NASA Johnson Space Center (JSC). ARES staff member backgrounds cover essentially all of the physical sciences (physics, chemistry, astronomy, geology), plus biology, mathematics, computer science, and engineering. ARES staff conduct basic research in earth, planetary, and space sciences and have curatorial responsibility for all NASA-held extraterrestrial samples. The collection includes approximately 382 kg of lunar material returned from the Apollo missions as well as meteorites and cosmic dust. Some of the meteorites are of lunar origin and a few have been confirmed to have originated on Mars. ARES staff also participates in robotic planetary missions as Principal or Co-Investigators, and instrument scientists. ARES also supports human space flight aboard the Space Shuttle and International Space Station (ISS). Additionally, in 2003 the Advanced Space Propulsion Laboratory (ASPL) was added to the ARES Office. The ASPL staff performs research in plasma physics with specific focus on developing magnetoplasma rocket technology.

JSC is a Center of Excellence for Astromaterials (samples of other bodies in our solar system) and has been responsible for curation of the precious Apollo lunar samples since 1969. The Lunar Sample Facility and other curation cleanrooms, laboratories and associated instrumentation are unique NASA resources. The curation efforts are greatly enhanced by a strong group of planetary scientists who conduct peer-reviewed astromaterials research. Curation not only consists of the long term care of the samples but also the development of new curatorial techniques and associated laboratories, support to sample return mission planning and the basic research that allows ARES scientists to provide a service to the external research community who rely on access to the samples. ARES was also a member of the NASA Astrobiology Institute, a virtual research institute studying the origin of and search for life in the universe. ARES scientists published the first paper on the possible evidence of life in a martian meteorite. The issue remains unresolved and highly controversial, but the research essentially invented the field of Astrobiology and invigorated the associated research.

ARES is a world leader in orbital debris research, including modeling, monitoring, and designing debris shielding. ARES researchers led the impact testing of the foam on Orbiter thermal protection surfaces that resulted in the conclusive demonstration of the cause of the Columbia accident. Additionally, the ARES Image Analysis Team was recognized as world class this year as a result of their contributions to the Columbia mishap investigation. ARES earth scientists manage the database of astronaut photography that is predominantly from Shuttle and ISS missions, but includes the results of 40 years of human space flight. The Earth observations web site continues to receive more than 10 million hits per month. ARES scientists are also active in the planning of future human exploration of the Moon and Mars through the study of analog activities in collaboration with Engineering and Flight Operations disciplines at JSC.

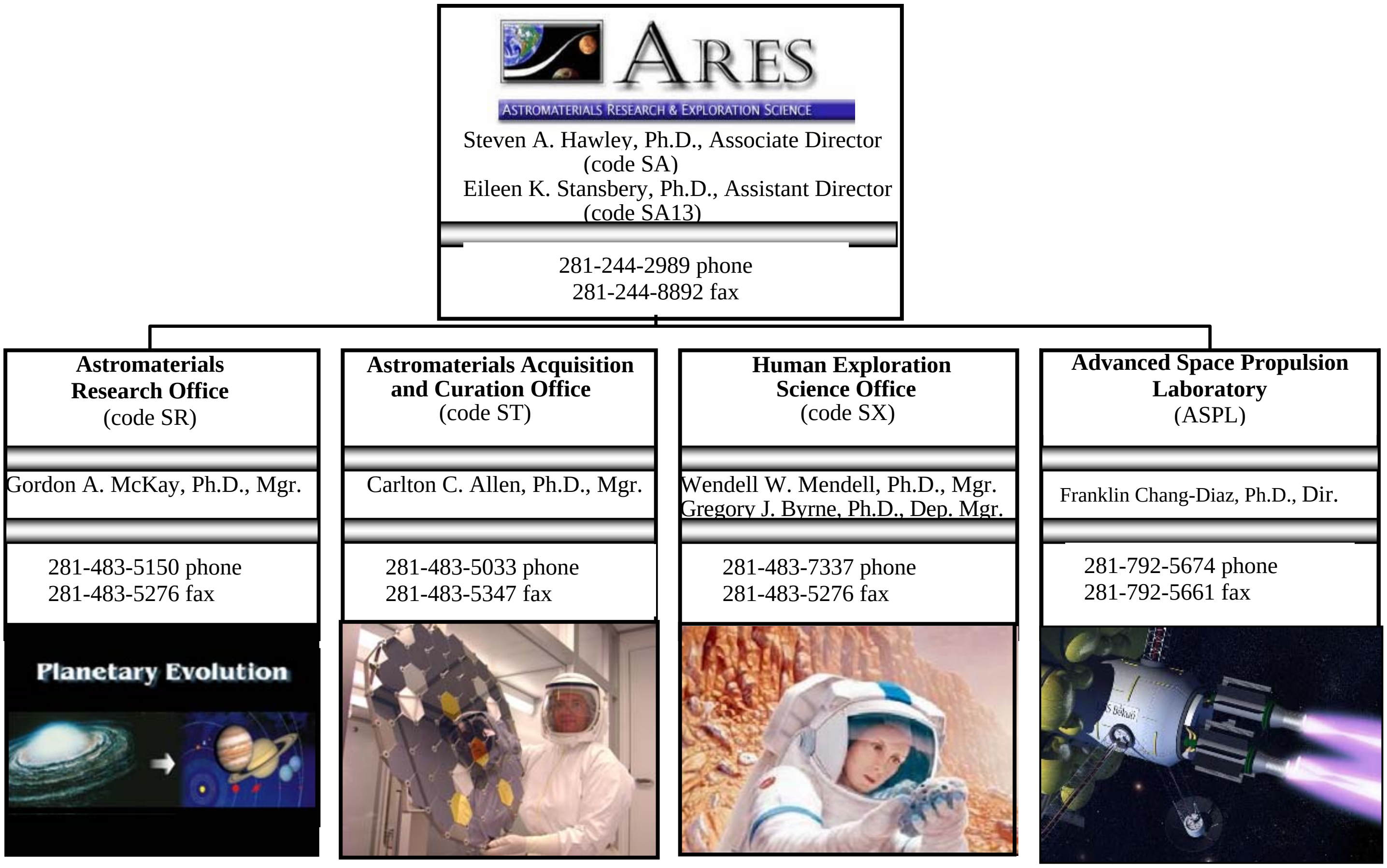
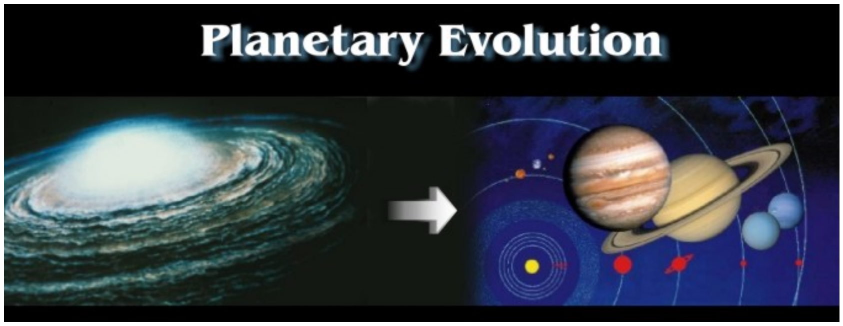


Figure 1. Astromaterials Research and Exploration ScienceOrganization Chart

ARES is organized into four offices (see Figure 1): Astromaterials Research (SR), Astromaterials Acquisition and Curation (ST), Human Exploration Science (SX) and the Advanced Space Propulsion Laboratory (ASPL). Each has multiple research goals and functions. SR staff conducts basic research in astromaterials and astrobiology and shares the results through education and outreach. ST staff manages curation of current astromaterials collections, plans for future collections, and conducts basic research. SX staff conducts research in Earth and image science and space debris, supports Shuttle and ISS missions, and plans for future human exploration of the Moon and Mars. The ASPL has responsibility for the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) project and associated research.

ARES continues to host numerous students and visiting scientists as a part of services provided to the research community and ARES conducts a robust education and outreach program. ARES scientists are recognized nationally and internationally by virtue of their success in publishing in peer-reviewed journals and at winning competitive research proposals. Twenty-two ARES scientists are Principal Investigators (PI) on peer reviewed proposals. ARES scientists have won every major award presented by the Meteoritical Society, including the Leonard Medal, the most prestigious award in planetary science and cosmochemistry, and the Nier Prize for outstanding research by a young scientist. ARES has established numerous partnerships with other NASA Centers, universities, and national laboratories. ARES scientists serve as society officers, journal editors, and members of advisory panels and review committees.

This Annual Report summarizes programs in each of our offices including ARES participation in sample return missions that will return the first extraterrestrial samples since Apollo 17, the Mars exploration program, and the development of new missions to be launched later this decade.



Astromaterials Research Office (SR)

Gordon A. McKay, Ph.D., Manager
http://ares.jsc.nasa.gov/AstroResearch/intro.html

The staff of the Astromaterials Research Office conducts peer-reviewed research in astromaterials and astrobiology. Scientists are funded through basic science disciplines of the NASA ROSS NRA (http://research.hq.nasa.gov/code_s/nra/current/), particularly Cosmochemistry, but also Origins, Exobiology, Planetary Geology, and Planetary Astronomy. Further funding comes from planetary missions, instrument development, and data analysis programs.

The fundamental goals of our research are to understand the origin and evolution of the solar system and the nature and distribution of life in the solar system. Our research involves analysis of, and experiments on, astromaterials in order to understand their nature, sources, and processes of formation. Our state-of-the-art analytical laboratories include four electron microbeam labs for mineral analysis, four spectroscopy labs for chemical and mineralogical analysis, and three mass spectrometry labs for isotopic analysis. Other facilities include the experimental impact laboratory and both one-atmosphere gas mixing and high-pressure experimental petrology labs. Recent research has emphasized a diverse range of topics, including

- study of the solar system's primitive materials such as carbonaceous chondrites and stratospheric dust
- study of early solar system chronology using short-lived radioisotopes
- study of large-scale planetary differentiation and evolution through study of siderophile element partitioning and isotopic systematics
- study of the petrogenesis of martian meteorites through petrographic, isotopic, chemical, and experimental melting studies
- interpretation of remote sensing data, especially from current robotic Mars missions, through study of terrestrial analog materials
- study of the role of biological systems in evolution of astromaterials

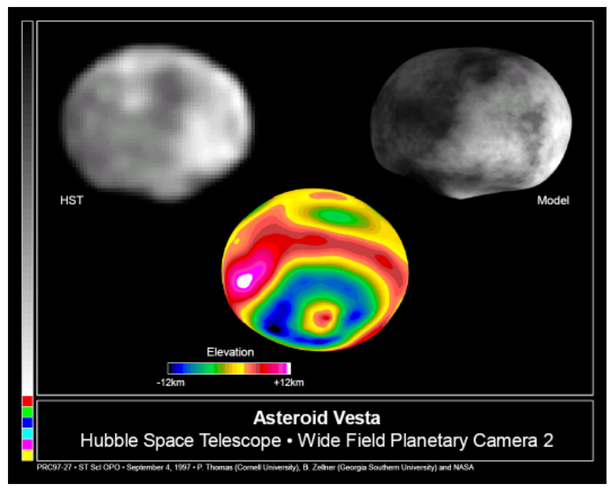
The following reports give examples of astromaterials research done by members of this and other ARES offices.

The Impact History of Asteroid 4-Vesta

Donald Bogard

Eucrite meteorites are igneous rocks that derive from a large asteroid, probably 4 Vesta. Prior studies have shown that after eucrites formed ~4.56 giga-years (Gyr) ago, most were subsequently metamorphosed to temperatures up to ~800^{o}C, and much later many were brecciated and heated by large impacts into the parent body surface. The less common basaltic, unbrecciated eucrites also formed near the surface but presumably escaped later brecciation, whereas the cumulate eucrites formed at depth where metamorphism may have persisted for a considerable period.

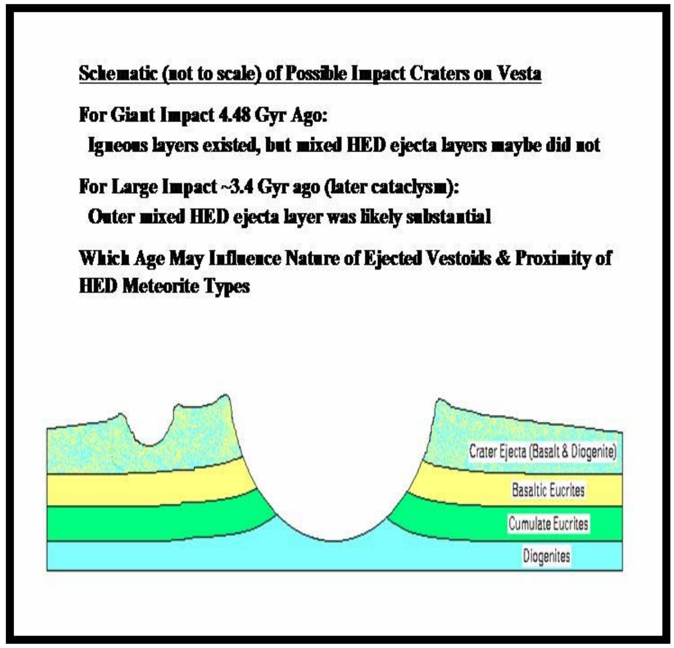
To further understand the complex HED parent body thermal history, we measured ^{39}Ar-^{40}Ar ages for nine eucrites classified as basaltic but unbrecciated, six eucrites classified as cumulate, and several basaltic-brecciated eucrites. The ^{39}Ar-^{40}Ar method is a variant of K-Ar dating and is sensitive to moderate thermal events, including heating produced during impacts into surfaces. Precise Ar-Ar ages of two cumulate eucrites and four unbrecciated eucrites give a tight age cluster at 4.48 ±0.02 Gyr. Ar-Ar ages of six additional unbrecciated eucrites are consistent with this age, within their relatively larger age uncertainties.



Asteroid Vesta

In contrast, available literature data on Pb-Pb isochron ages of four cumulate eucrites and one unbrecciated eucrite vary over 4.4-4.515 Gyr, and ^{147}Sm-^{143}Nd isochron ages of four cumulate and three unbrecciated eucrites vary over 4.41-4.55 Gyr. Similar Ar-Ar ages for cumulate and unbrecciated eucrites imply that cumulate eucrites do not have a younger formation age than basaltic eucrites, as previously proposed. Rather, we suggest that these cumulate and unbrecciated eucrites resided at depth in their parent body (presumably Vesta), where temperatures were sufficiently high to cause the K-Ar and some other chronometers to remain open diffusion systems. From the strong clustering of Ar-Ar ages at ~4.48 Gyr, we propose that these meteorites were excavated from depth in a single large impact event ~4.48 Gyr ago, which quickly cooled the samples and started the K-Ar chronometer. A very large (~460 km diameter) crater observed on Vesta may be the source of these eucrites and of many smaller asteroids, called vestoids, thought to be spectrally or physically associated with Vesta. Some Pb-Pb and Sm-Nd ages of cumulate and unbrecciated eucrites are consistent with the 4.48 Gyr Ar-Ar age, and the few older Pb-Pb and Sm-Nd ages may reflect isotopic closure prior to the large cratering event.

Most basaltic eucrites are breccias formed by repeated impacts, and these typically show impact-reset Ar-Ar ages in the range of 3.4-3.7 Gyr. New Ar-Ar analyses of three cumulate eucrites and several basaltic eucrites give Ar-Ar ages consistent with this age range. We attribute all these younger ages to impact heating that occurred in an enhanced or cataclysmic bombardment of the inner solar system over the period of ~4.0-3.4 Gyr ago. An impact cataclysm has been proposed to have occurred on the moon ~4.0-3.8 Gyr ago. The onset of major impact heating may have occurred at similar times for both Vesta and the moon, but impact heating appears to have persisted to a somewhat later time on Vesta compared to the moon. Age dating of eucrites and lunar highland rocks currently offers the only method to characterize this impact cataclysm, which not only strongly influenced the early crustal development of all the inner planets, but also may have influenced the development of life on Earth.



Schematic (not to scale) of Possible Impact Craters on Vesta

We also used the Ar isotopic data obtained in age dating these eucrites to calculate their cosmic-ray, or space exposure ages. These CRE ages are calculated from Ar that forms as a result of nuclear reactions produced from high-energy cosmic ray irradiation of objects in space. The CRE ages of eucrites range over ~4-50 mega-years (Myr) and measure the time that elapsed between meteorite ejection by impact from a parent body and their arrival on Earth. Because Vesta is located in an orbit that makes it difficult to eject meteorites directly to earth, and because smaller asteroids, called vestoids, are located in dynamically more favorable orbits and are spectrally very similar to Vesta, vestoids are believed to be the direct parent bodies of eucrites. We suggest that vestoids were ejected from Vesta by the early Ar-Ar dated impacts, i.e., prior to 3.4 Gyr ago. Eucrites are related to several other meteorite types, which collectively comprise a meteorite suite called HEDs that formed at different depths of ~0-20 km inVesta. About one-third of HEDs possess a common CRE age of ~21 Myr. This implies that the immediate vestoid parent of HEDs contains all HED meteorite types, which were sampled by the ~21 Myr impact event, which itself must have been of significant size.

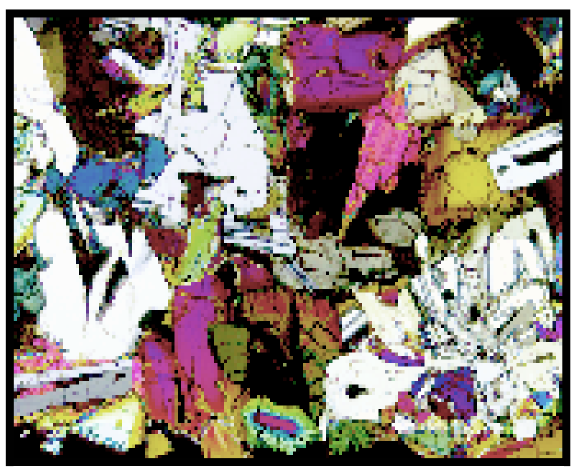
The NASA Discovery Program is developing a robotic mission called DAWN that will orbit Vesta and determine several of its characteristics.

J.H. Jones[1], D.W. Mittlefehldt[1], A.J.G. Jurewicz[2], T. Mikouchi[3], G. Crozaz[4], G.A. McKay[1], and L. Le[1]

The angrites are an important and unusual group of basaltic igneous meteorites that are like no other rocks anywhere. Their ages are ancient and their mineralogies are strange. The deciphering of this meteorite group is an interesting story in which ARES is prominently involved. The angrite story also re-emphasizes a truism of scientific research: many different bits and pieces have to fit together, like a jigsaw puzzle, and this fitting often takes time.

The importance of the angrites stems from their ancient origins, ~4,556 million years ago. These are some of the oldest rocks and, therefore, they record the presence of short-lived radioactive isotopes that only existed during the first few million years of the early solar system. The angrites are also used to define the initial Pb isotopic composition of our solar system — a quantity that is necessary in order to do U-Pb dating. Therefore, understanding the origins of these strange basalts has far-reaching implications.

But angrites are so strange that, for decades, their origins were obscure. This was not helped by the fact that the first angrite, Angra dos Reis, is unusual — even for an angrite. Angra dos Reis consists almost entirely of fassaitic pyroxene (a type of clinopyroxene that is rich in Al and Ti — elements that normally do not readily enter pyroxene). Angra dos Reis fell in Brazil in 1869 but the next angrite, LEW86010, was not found until 1986 in the Lewis Cliff region of Antarctica (whence its name). But even "normal" angrites have weird mineralogy for basalts. The olivine in angrites is very calcium rich, and the plagioclase feldspar has almost no sodium (because the rock itself has almost no sodium), and angrites are rich in FeO and critically undersaturated with respect to SiO_2. Therefore, in addition to studying angrites because of their ancient ages, we also study them because they're weird. Scientists do that sometimes.

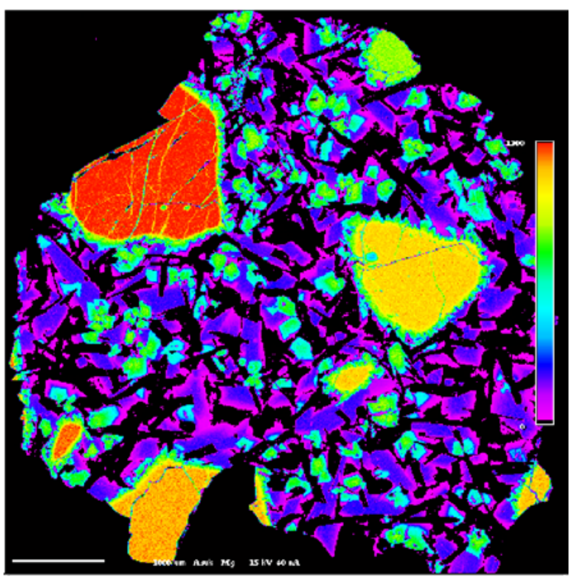


Polarized light photomicrograph of D'Orbigny. Light gray or white grains are plagioclase and brightly colored grains are olivine or pyroxene. Width of image is about 2mm.

Many people initially reached the wrong conclusion as to how to make angrites, so it's hard to point a finger at any one person. The only other meteorite samples commonly known to contain fassaitic pyroxene were the Calcium-Aluminum-Rich Inclusions (CAI) of the Allende chondrite. Therefore, many people felt that Angra dos Reis came from a planet that was unusually enriched in CAI material. And remember that, until 1986, the only angrite people had ever seen was Angra dos Reis which is weird even by angrite standards.

The first person to reach the right conclusion was ARES scientist David (Duck) Mittlefehldt. About 1990, after the finding of LEW86010 and LEW87051 (a third angrite), Duck reasoned from his petrologic studies of these meteorites that many of the strange properties of angrites could be understood if they formed under more oxidizing conditions. This could make them more FeO rich than “normal” meteorite basalts and this enrichment in FeO might cause angrites to be silica (SiO_2) undersaturated. He, in turn, persuaded Amy Jurewicz and John Jones to do partial melting experiments on chondrites under oxidizing conditions (> Fe-FeO buffer) to see if they could make angrites that way. The answer was yes and no. Partial melts of Murchison at 1180-1200°C under oxidizing conditions looked a bit like the Antarctic angrites. Amy and John’s partial melts of Allende were even closer in composition, but nothing matched exactly. However, the notion that the angrites came from an oxidized source region was reinforced by the experiments and analyses of Gordon McKay and Ghislaine Crozaz, who inferred that LEW86010 formed just above the Fe-FeO buffer. This was the situation as of 1994.

In the meantime, more angrites were found. The Asuka881371, Sahara99555, and D’Orbigny angrites were found. Duck performed a petrologic study of D’Orbigny; and Takashi Mikouchi, Gordon McKay, and Loan Le did the same for Asuka881 371 and Sahara99555. What Takashi and Gordon found, using their and Duck’s data, was that the angrites other than Angra dos Reis (which was known to be weird) formed a trend of olivine addition. This was not surprising because some angrites were known to contain foreign (“xenocrystic”) olivines.



Magnesium map of Asuka 881371. Warmer colors indicate higher magnesium concentrations. Large red, orange, and green crystals are olivine. It is unusual that different olivine crystals have different magnesium contents. Sample is about 5 mm across.

This year, Takashi and Gordon also noticed that the apparent amount of olivine contamination did not exactly match the amount of olivine contamination observed. The inferred amount was usually greater, suggesting that, in addition to just suspending this contaminating olivine in the angrite magmas, some of the olivine had actually dissolved.

Their observation also implied that some angrites should be more primitive than others — the samples with the least contamination (D'Orbigny and Sahara99555) were probably closest. At about the same time, Amy and John noticed that the compositions of their Allende partial melting experiments looked remarkably like D'Orbigny, an angrite that was not known at the time of their experiments.

After 13 years, the genesis of angrites seems pretty well understood. Chondritic materials are partially melted under redox conditions where iron metal is unstable. Primitive angrites and experimental melts are remarkably similar in composition. However, most angrites have experienced contamination by foreign materials and these only vaguely resemble the experimental melts. New samples and persistence by the ARES team have combined to make a compelling angrite story. Other issues, though, such as the source of the contaminating xenocrysts, remain to be solved.

Cometary Dust in Astrophysics Research

Lindsay P. Keller, Scott R. Messenger and Keiko Nakamura

Interplanetary dust particles (IDPs) are the most pristine remnants of the original building blocks of the Solar System. IDPs are fragments of comets and asteroids that are far more fragile, carbon-rich and fine grained in comparison with meteorites. The specific parent bodies of IDPs are unknown, but the anhydrous subset has been linked directly to comets. These IDPs have escaped the extensive thermal processing and water-rock interactions that have obscured the original mineralogy and chemistry of meteorites. For the past 20 years, NASA has routinely collected these particles in the Earth's stratosphere with high-altitude research aircraft. Although only 1/10 the diameter of a human hair (~50 micrometers), these particles are comprised of thousands to millions of sub-micrometer subcomponents, many of which originated before the birth of our Solar System.

Preserved samples of interstellar molecules and stardust have been identified in IDPs, marked by their exotic isotopic compositions. Isotopic imaging studies of IDPs have identified interstellar silicate grains (Fig. 1) that formed in the massive winds of red giant stars and perhaps supernovae. These grains have isotopic compositions that reflect the nucleosynthetic processes in their parent stars, and are thus easily distinguished from material formed in our Solar System. By combining such isotopic studies with many other types of analyses – most importantly transmission electron microscopy (TEM) – we can learn about the mineralogy, chemistry and structure of these materials on an atomic scale.

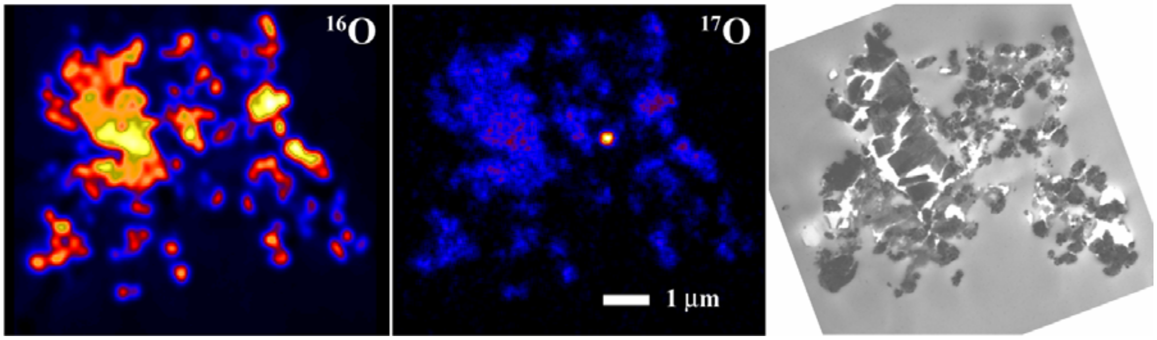


Figure 1: Oxygen isotopic images of a 70 nanometer-thick slice of an interplanetary dust particle. A grain of stardust is clearly distinguished by its extreme enrichment in ^{17}O. The image at the right was acquired by TEM and was used to determine the composition of the stardust grain.

So far, we have identified six silicate grains within IDPs that predate our Solar System. Their extrasolar origins are demonstrated by their extremely anomalous oxygen isotopic compositions. Three ^{17}O-rich grains appear to have originated from asymptotic giant branch stars. One ^{16}O-rich grain may be from a metal-poor star. Two ^{16}O-poor grains have unknown stellar sources. One of the grains is forsterite, and the other two are glassy silicates, which is consistent with astronomical identifications of crystalline and amorphous silicates in the outflows of evolved stars. These observations suggest cometary origins of these IDPs, and underscore the perplexing absence of silicates among circumstellar dust grains from meteorites.

We have also identified material that formed in the cold interstellar molecular cloud that gave birth to our Solar System. Astronomical observations have shown that these clouds are sites of vigorous chemical processes, despite ambient temperatures (10 – 100 K) near absolute zero. At such low temperatures, the heavy isotope of hydrogen (deuterium) forms stronger bonds than the light isotope, leading to enormous isotopic fractionation during chemical reactions. Isotopic imaging studies have located small nuggets of pristine molecular cloud material, preserved in some IDPs (Fig. 2). By carefully extracting this material we have found it to be primarily composed of organic compounds similar to those found in primitive meteorites.

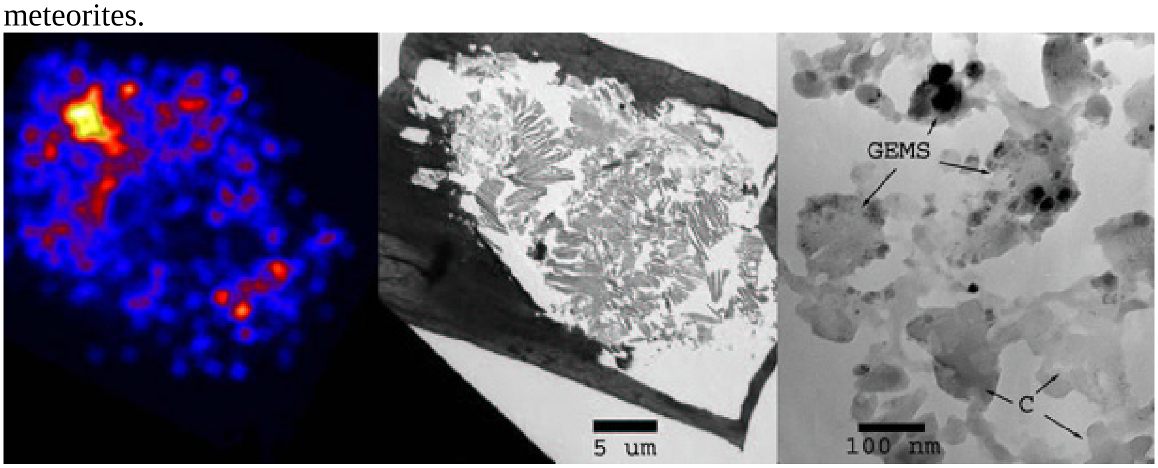
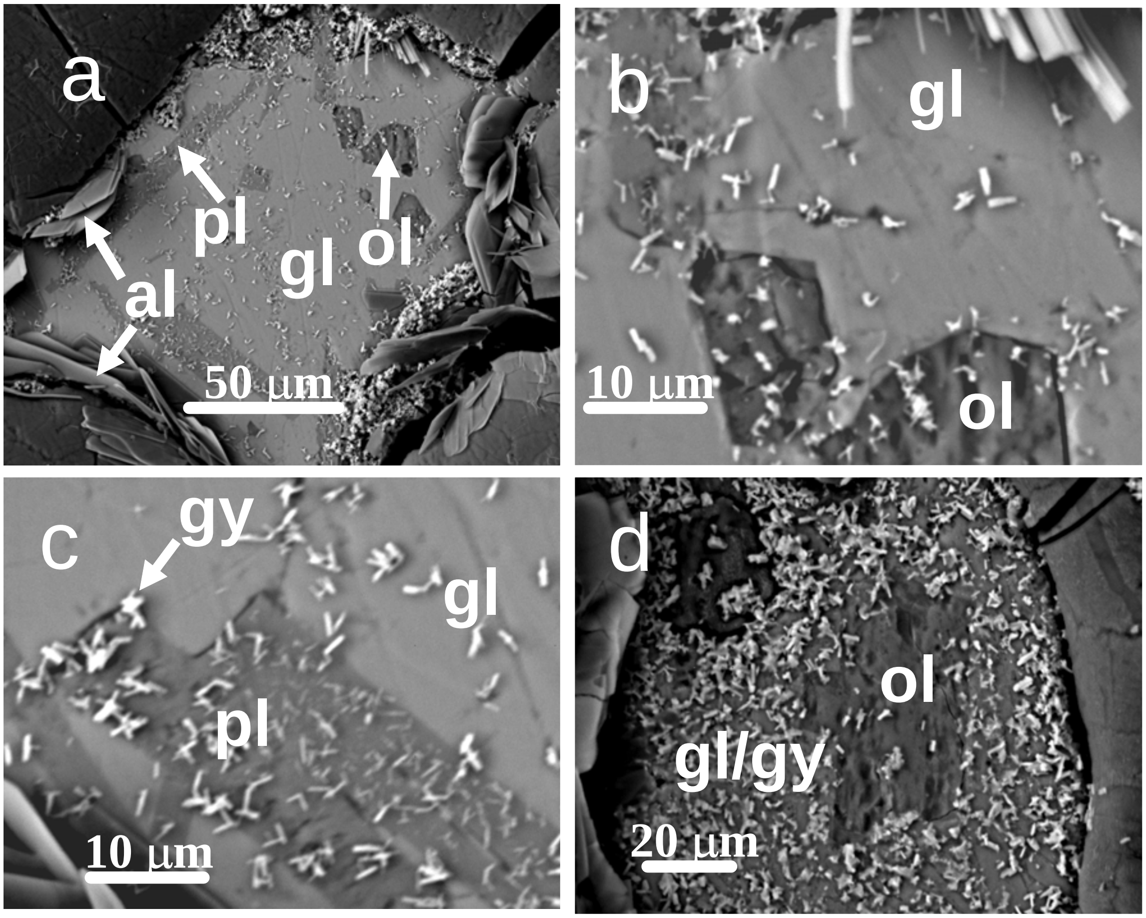


***Figure X. Left: D/H ratio image of an IDP acquired with the ion microprobe showing micrometer scale hotspots of D-rich material. Middle: TEM image of a thin section of the same particle and some of the surrounding gold from the sample mount. The thin section was obtained using ultramicrotomy. Right: Higher magnification TEM image of the material within the D-hotspot showing abundant organic material and silicate grains*.**

The identity and properties of circumstellar grains are inferred from spectral comparisons between astronomical observations and laboratory data from natural and synthetic materials. In cold, dense interstellar molecular clouds, the nursery of young stellar objects (YSOs) like the solar nebula, sulfur is observed to be highly depleted from the gas phase and is assumed to be present within solid grains, although the nature of the condensed S-bearing phase(s) is unknown. We measured the infrared spectral properties of Fe-sulfides in IDPs and terrestrial standards and compared them to astronomical data from ESA's ISO (Infrared Space Observatory) mission. These data show that Fe-sulfides are the main carrier of condensed S in circumstellar disks, YSOs, and comets.

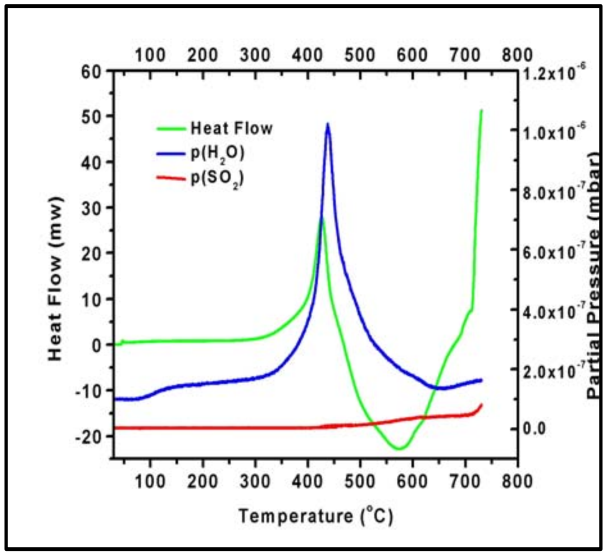
Experimental studies of the interaction of acidic volatiles and fluids with Mars surface materials. Sulfur is a major chemical component of the Martian surface and is thought to have a volcanic origin (e.g., SO_2 and acid-sulfate vapors and aerosols); however, the mineralogy of sulfur-bearing phases on Mars is not known. D. C. Golden, Doug Ming, and Dick Morris are conducting laboratory experiments to constrain the sulfur mineralogy on Mars. Mars analog materials (e.g., olivine- and plagioclase-rich volcanic tephra samples) are subjected to possible sulfuric-acid weathering processes on Mars, including weathering in closed hydrologic systems (i.e., no leaching of water through the material), in open hydrologic systems (i.e., water leaches through the material), and sulfatera systems (i.e., sulfuric-acid vapors interact with materials). We have shown that olivine-rich basaltic tephra altered under oxidative, acid-sulfate conditions yielded jarosite (Fe-sulfate) and gypsum (Ca-sulfate) in an open hydrologic system and amorphous silica in a closed hydrologic system. Plagioclase-rich and olivine-rich basaltic tephra altered to alunogen (hydrated Al-sulfate), Mg-sulfate salts (i.e., hexahydrite, epsomite), gypsum, and amorphous silica after interactions with sulfuric-acid vapors. The reaction products are being characterized by a variety of remote sensing techniques. These results will aid in interpreting the remote sensing data returned from Mars Robotic missions and thus enhance our quest to identify the sulfur-bearing phases in the martian regolith.



***Scanning electron microscope images of olivine-rich basaltic matrial that has been subjected to alteration by sulfuric acid vapors. Mineral identification codes: pl=plagioclase; gl=glass; ol=olivine; al=alunogen; gy=gypsum*.**

Search for water and other volatile-bearing phases in Mars surface materials: Analogue and experimental studies. The theme of the Mars Exploration Program is to "follow the water," which has important implications in the search for life, climate evolution, evolution of the Martian surface and interior, and preparing for human exploration. The two Viking Landers discovered small amounts of water (e.g., 1-2 wt. %) in the surface materials, however, it is not known how the water is incorporated into these materials. Recently, Mars Odyssey results have shown that water in the form of ice may be very near the surface (e.g., 20-30 cm below the surface) at high latitudes (e.g., above 60˚). Again, we do not know how the water is incorporated into these materials (e.g., ice, adsorbed water, structural water). Doug Ming, Dick Morris, and Vern Lauer are conducing research on the thermal and evolved gas behaviors of Mars analogue materials (i.e., minerals and "soils").

Thermal behavior and evolved gas contentrations during heating of a Mars analog material.



Current research tasks are to 1) determine the thermal and evolved gas behaviors of Mars analog minerals at Earth-ambient and Mars-like surface pressures; 2) determine the thermal and evolved gas analysis of Mars analog "soils" from near the summit of Mauna Kea Volcano in Hawaii; and 3) develop a thermal and evolved gas dataset in support of the Mars Exploration Program. Results obtained from this proposed effort will provide important implications on the nature of water and other volatiles (e.g., CO_2, SO_2) in the Martian surface materials and provide viable geologic pathways for their formation. Thermal and evolved gas behaviors of Mars analog materials will also provide critical "feed forward" information on the possible mineralogy and chemistry of Mars surface "weathering" phases that will enhance the planning for instruments and investigations on future Mars robotic missions (i.e., 2007 Phoenix Mars Scout, 2009 Mars Science Laboratory).

Mineralogical and chemical composition of the Martian surface through using Martian analogue materials from the Earth and the Moon. One way to understand the chemical and mineralogical composition of Mars and the processes that brought them to their current state is to study Martian analogue samples from other planetary bodies. Dick Morris and Doug Ming are conducting analogue studies on samples from the Island of Hawaii and on samples from the Moon.

Mars analog materials on Hawaii

Based on studies of Martian meteorites and direct analysis of Martian surface materials by Viking and Pathfinder landed instruments, the surface of Mars is basaltic in composition. The Island of Hawaii also has a basaltic composition, and analysis and identification of primary and aqueous and hydrothermal alteration phases found there provide a template for identification of those phases on Mars. Because the elemental and mineralogical composition of basaltic alteration products depend to a large extent on the specific nature of alteration processes, the analogue samples also provide information about the type and timing of alteration processes on Mars. Certain lunar samples have mineral assemblages that are more similar to Martian meteorites than natural terrestrial samples, especially with respect to the mineral pigeonite. Because aqueous alteration has not taken place on the Moon, lunar samples are a “Mars without water” zero-point for Martian alteration processes.

Mars Robotic Exploration

Richard V. Morris and Doug W. Ming

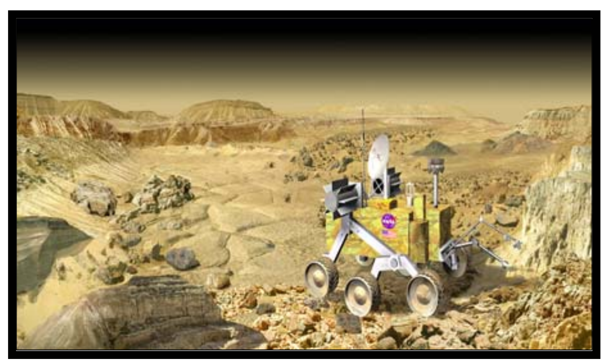
ARES scientists are actively involved in all aspects of Mars Robotic Exploration, including the 2003 Mars Exploration Rovers Mission, 2003 Mars Express/Beagle 2, 2005 Mars Reconnaissance Orbiter, 2007 Phoenix Scout Mission, and the 2009 Mars Science Laboratory.

2003 Mars Exploration Rovers. Two ARES scientists, Dick Morris and Doug Ming, are on the science team (as co-investigator and participating scientist) for the twin MER Rovers. The two rovers landed on Mars in January of 2004 in the Meridiani Planum and Gusev Crater regions of Mars. The mineralogy and chemistry of the two landing sites are being characterized via the Athena remote sensing instruments on each rover. A target of well-characterized samples was developed by ARES scientists to validate the performance of the Athena remote sensing instruments. During mission operations, ARES scientists are responsible for development of daily scientific observations and commands for uplinking to the rovers as well as preparing downlink data products from several of the Athena instruments.

2003 Mars Express/Beagle 2. Dick Morris was on the team for the Moessbauer spectrometer instrument on the Beagle 2 Mars Express lander and Everett Gibson participated as the interdisciplinary scientist. Beagle 2 landed in December of 2003, but has not been heard from since. The Moessbauer spectrometer would have provided key information about the mineralogical composition of iron-bearing phases in the Isidis region of Mars. Dr. Morris is also a collaborator on the OMEGA instrument on the Mars Express orbiter. OMEGA is a visible-infrared hyperspectral mapper. The ARES scientist participates in interpretation of data and in development of spectral libraries for the mission.

2005 Mars Reconnaissance Orbiter. Dr. Morris is also a co-investigator on the CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) instrument that is one component of the Mars Reconnaissance Orbiter 2005 mission. CRISM, which is a visible-infrared hyperspectral mapper (~25 m/pixel), will "Follow the Water" by searching for evidence of aqueous and hydrothermal deposits and by mapping the geology, composition, and stratigraphy of surface features. CRISM will also characterize seasonal variations in opacities of dust and ice aerosols and will track any seasonal changes in the water content of surface materials. Dr. Morris participates in instrument calibration, mission operations, and data interpretation, which is based in part on databases developed at JSC.

2007 Phoenix Scout Mission. Doug Ming and Dick Morris are both co-investigators on the 2007 Phoenix Scout Mission. Phoenix will land at a high northern latitude in search of the near-surface ice that has been discovered by the Mars Odyssey science team from neutron and alpha-particle spectrometer measurements obtained from the orbiter. Hence, Phoenix will "Follow the Water" and study the history of water in all of its phases with chemical, geological and meteorological measurements. In addition, Phoenix will search for habitable zones by assessing the organic or biological potential of the landing site. Drs. Morris and Ming will be responsible for the calibration of the Phoenix instruments and will develop science strategies for the mission. In addition, Dr. Ming is currently the chair of the Phoenix Chemistry and Mineralogy Science Theme Group.



2009 Mars Science Laboratory. The 2009 Mars Science Laboratory (MSL) will likely have an analytical laboratory on a rover that will have much greater roving and analytical capabilities than the Mars Exploration Rovers. The analytical laboratory will have the capability to 1) assess the biological potential (e.g., nature and inventory of organic carbon compounds, inventory of chemical building blocks of life, characterize biologically relevant processes); 2) characterize the geology of the landing region at all appropriate spatial scales (e.g., determine chemical, isotopic, mineralogical compositions; characterize rock and regolith forming processes); and 3) investigate planetary processes that influence habitability (e.g., atmospheric evolution, present state, distribution, and cycling of water and carbon dioxide). Drs. Ming and Morris are actively working with several instrument teams to design analytical instruments that address the objectives for the 2009 MSL.

Astromaterials Acquisition and Curation Office (ST)

Carlton C. Allen, Ph.D., Manager
http://curator.jsc.nasa.gov/

JSC and the Curatorial team are responsible for the curation of NASA's current collection of astromaterials that includes lunar samples collected by the Apollo astronauts, meteorites collected in Antarctica, cosmic dust collected in the stratosphere, and hardware exposed to the space environment. Curation comprises initial characterization of new samples, preparation and allocation of samples for research and education, and clean, secure storage of samples at JSC or remote sites. The foundations of our curation are the specialized cleanrooms (class 10 to 10,000) for each of the four types of materials, the supporting facilities, and the people, many of whom have been doing detailed work in ultraclean environments for many years.

JSC is also responsible for curation of extraterrestrial samples collected on all future NASA missions. The Curatorial team is also preparing to curate the next generation of extraterrestrial samples. JSC has been designated as the curation site for solar wind (Genesis), comet (Stardust), and asteroid (Hayabusa) samples collected by future NASA and international spacecraft missions. Additional missions have been proposed to sample the far side of the Moon, the dust and gas in the atmosphere of Mars, and the surfaces of comets and asteriods. ARES is also active in planning for post-mission sample handling and curation of samples returned by future Mars surface missions. The Curatorial team is conducting research and development of advanced concepts for curating all of these new sample collections.

The following reports give updates on curation of current astromaterials collections and plans for future collections.

Astromaterials Curation

Curators: Carlton Allen, Gary Lofgren, Kevin Righter, Michael Zolensky

Astromaterials curation is the cornerstone of the NASA Cosmochemistry research program. ARES staff curates the existing collections and distributes them to researchers worldwide to investigate the origin and evolution of the solar system.

Lunar Samples

Gary E. Lofgren, Andrea B. Mosie and Linda A. Watts

Lunar Sample Laboratory

The Apollo astronauts collected 2196 Moon rock and soil samples having a total mass of 382 kg. They are the only documented samples yet returned from another body in the solar system. JSC Astromaterials staff curates this national treasure in the Lunar Sample Facility, a suite of class 1000 cleanrooms and secure vaults constructed in 1979. The collection now comprises approximately 100,000 subsamples, many of which are located in research laboratories and museums worldwide. The bulk of the collection, including pristine samples and material returned following analysis, is stored at the JSC facility. Even 30 years after the Apollo missions, lunar sample research is active, with new techniques yielding new insights into the history of the Earth-Moon system.

Antarctic Meteorites

Kevin Righter, Cecilia E. Satterwhite and Kathleen McBride

Antarctic meteorite collection

Meteorites are rocks from space that have fallen on Earth. Since 1976, the U.S. has sent yearly expeditions to Antarctica to recover meteorites. (Glacial movement concentrates meteorites on icefields near mountain ranges.) The Antarctic Meteorite Program is a collaboration between the National Science Foundation (NSF), Smithsonian Institution, and NASA in which NSF is responsible for collection and NASA and SI share curation duties. ARES' role is initial description, temporary storage, and distribution of samples to investigators. This is performed in a dedicated suite of class 1000 cleanrooms. The meteorites are eventually sent to the Smithsonian Institution for permanent storage after demand for an individual sample has decreased, but JSC curates over 4,000 specimens at any one time. The number of new samples collected by a single field team and delivered to JSC each year has ranged from approximately 200 to well over 1000, including five meteorites from Mars and eight from the Moon. The 2002-2003 team returned 925 new meteorites from the ice.

Cosmic Dust

Michael E. Zolensky and Jack L. Warren

Microscopic particles of comets and asteroids, captured by the Earth and suspended in the stratosphere, are collected by dedicated equipment on two NASA aircraft. The collectors are prepared at JSC and returned to the JSC Cosmic Dust Laboratory, a class 100 cleanroom, where individual particles are retrieved, documented, and distributed to researchers. The Cosmic Dust program has operated since 1981.

Space-Exposed Hardware

Michael E. Zolensky, Jack K. Warren and Thomas H. See

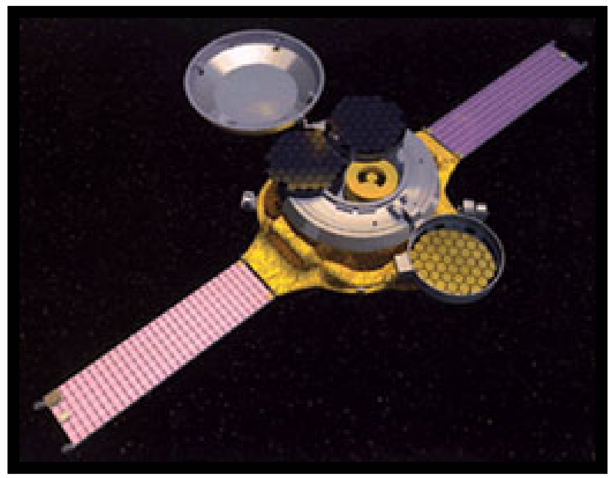
Since 1970, JSC has prepared and distributed a diverse collection of materials that have been exposed to the space environment. These have included pieces of the Surveyor 3 spacecraft sampled by the Apollo 12 astronauts, the Long-Duration Exposure Facility, several commercial satellites retrieved by the Space Shuttle, and materials from the Mir space station. Documentation and curation of these materials is done in the Facility for Optical Inspection of Large Surfaces.

Genesis — Solar Wind Sample Return

Eileen K. Stansbery

Genesis is a spacecraft mission to collect atoms and ions of the solar wind, the extended atmosphere of the Sun. When it returns to Earth in 2004, Genesis will bring NASA's first spacecraft-collected samples since Apollo 17 in 1972, and the first ever material returned from deep space. ARES curation personnel are essential members of the Genesis Science Team. ARES responsibilities are contamination control and curation. To accomplish these tasks JSC built two ultraclean class 10 cleanrooms, NASA's cleanest laboratories. In 2000 the Genesis payload was dismantled, cleaned, and reassembled in these special cleanrooms (see photo in curation overview).

After its August 2001 launch, the Genesis spacecraft began its journey sunward. It then entered a stable orbit at a point in space, about 1 million miles from Earth in the direction of the Sun, where the gravities of Earth and the Sun balance. The spacecraft unfolded its collectors and has "sunbathed" for two years, collecting atoms from the solar wind.



Genesis spacecraft

Genesis carries four instruments: bicycle-tire-sized solar-wind collector arrays, made of materials such as diamond, gold, silicon and sapphire, and designed to entrap solar wind particles; an ion monitor, to record the speed, density, temperature and approximate composition of the solar wind ions; an electron monitor, to make similar measurements of electrons in the solar wind; and an ion concentrator, to separate and focus elements like oxygen and nitrogen in the solar wind into a special collector.

Sample collection concluded in April 2004, when the spacecraft began its return to Earth. In September of 2004, the samples will arrive on Earth in a dramatic helicopter capture. As the sample-return capsule parachutes toward the ground in Utah, specially trained helicopter pilots will catch the capsule in midair to prevent the delicate samples from being disturbed by the impact of a landing.

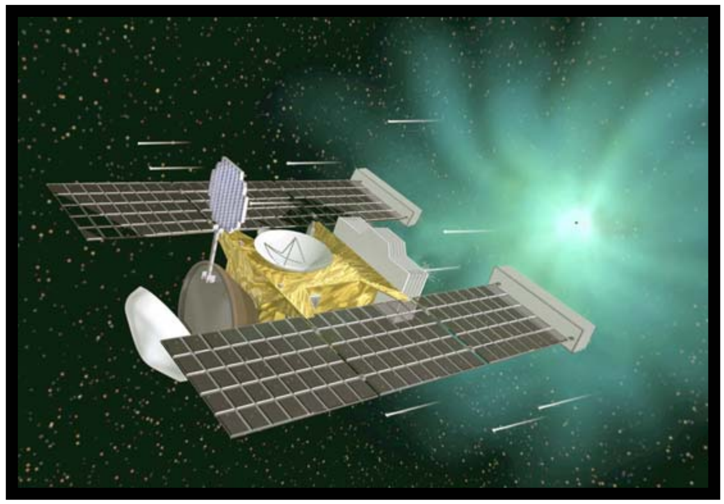
This treasured sample of the Sun will be opened, processed, and preserved in the JSC Genesis laboratory, and distributed for study to scientists in the next decade and over the next century. The atoms and ions will help scientists understand the composition of the original solar nebula that formed the planets, asteroids, comets and the Sun we know today.

Stardust — Comet Sample Return

Michael E. Zolensky and Friedrich P. Horz

Comets are believed to be the oldest, most primitive bodies in the solar system, possibly comprised of some of the basic building blocks of life. They contain the remains of materials from the formation of stars and planets, holding volatile, carbon-based rich elements that are likely to provide clues about the nature early solar system. Comets may have been the major source of water on the Earth, Mars and other worlds, making life possible.

With the prospect of comets offering this treasure house of ancient information, there is significant anticipation about what findings scientists will be able to extrapolate from a firsthand examination of cometary materials. Because the Stardust spacecraft will both return samples of material from a comet's dusty coma, and provide real-time in-flight data about what it encounters, there is a real possibility of scientific findings that will change the way we view our origins.



Stardust spacecraft

The Stardust spacecraft was launched in February 1999. In January 2004, Stardust flew about 300 km in front of the nucleus of Comet Wild 2, through the halo of gases and dust. During this passage the spacecraft will collect dust and volatiles. The comet samples are expected to consist of ancient pre-solar interstellar grains and nebular condensates that were incorporated into comets at the birth of the solar system.

In addition to the cometary samples, the spacecraft is also collecting interstellar grains during the cruise phase of the mission. This material flows into our solar system in a great river of dust and gas. Analysis of this material will permit us to greatly expand our knowledge of the evolution of stars, the birth of the chemical elements, and the history of our galaxy. This mission was the first sample return mission launched in 30 years and it collected the first material from deep space, yet because it is traveling a much greater distance than its sister Genesis mission, it will return two years later with its precious cargo.

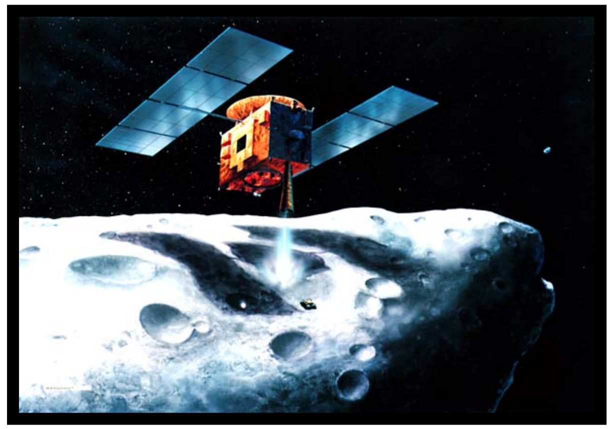
ARES scientists are key members of the Stardust Science Team. They helped develop and test the silica aerogel that is the magic material that will capture and hold the comet coma grains. This team has developed exacting techniques for the removal and analysis of captured grains from the silica aerogel. These scientists are also constructing the JSC curation lab which will receive the samples in 2006, and preparing for the preliminary analyses which will for the first time reveal the true nature of comets, their role in the early history of the solar system, and possibly, the origin of water and organic matter on Earth and Mars.

Hayabusa — Asteroid Sample Return

Michael E. Zolensky and Faith Vilas

The Hayabusa mission will be the first sample return mission by Japan's space science agency, The Japanese Aerospace Exploration Agency (JAXA), and has been developed jointly with NASA. The goal of the mission is to return chipped samples from the surface of a small near-Earth asteroid called Itokawa.

The spacecraft left Earth in May 2003, and will rendezvous with the near Earth asteroid in the summer of 2005. The entire spacecraft will briefly touch down on the surface 2 or 3 times. During each of these touch-and-go landings a projectile will be fired at the surface at a velocity of a 300 m/s, which will blast free a small quantity of material. This liberated sample could be powder or chips, if bedrock is exposed. In any case, on the order of 1g of material will be collected into a horn-shaped receptacle at each of the different sites.

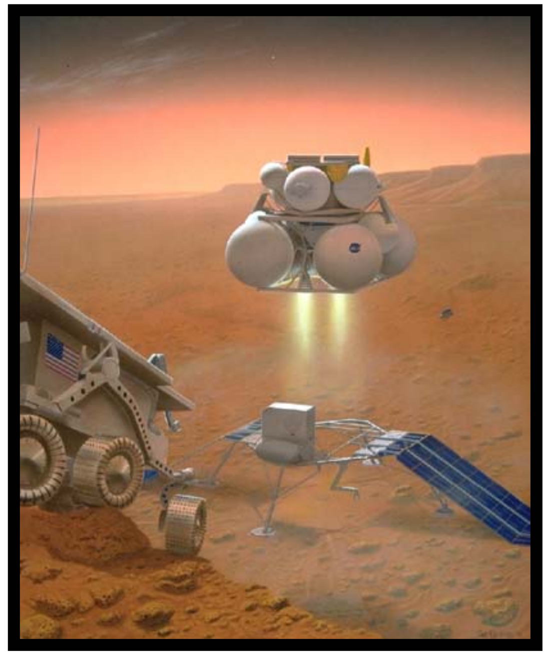


Hayabusa spacecraft

In 2007 the samples will be returned to Earth within a hermetically-sealed capsule, and flown to the JAXA lab for 1 year of preliminary investigation in Japan. Following this period the samples will be made widely available, with approximately 10% of the sample mass coming to JSC for curation and distribution. ARES scientists are members of the Hayabusa Science Team and are involved in both sample curation and characterization of the target asteroid.

Mars Returned Sample Handling

Carlton C. Allen



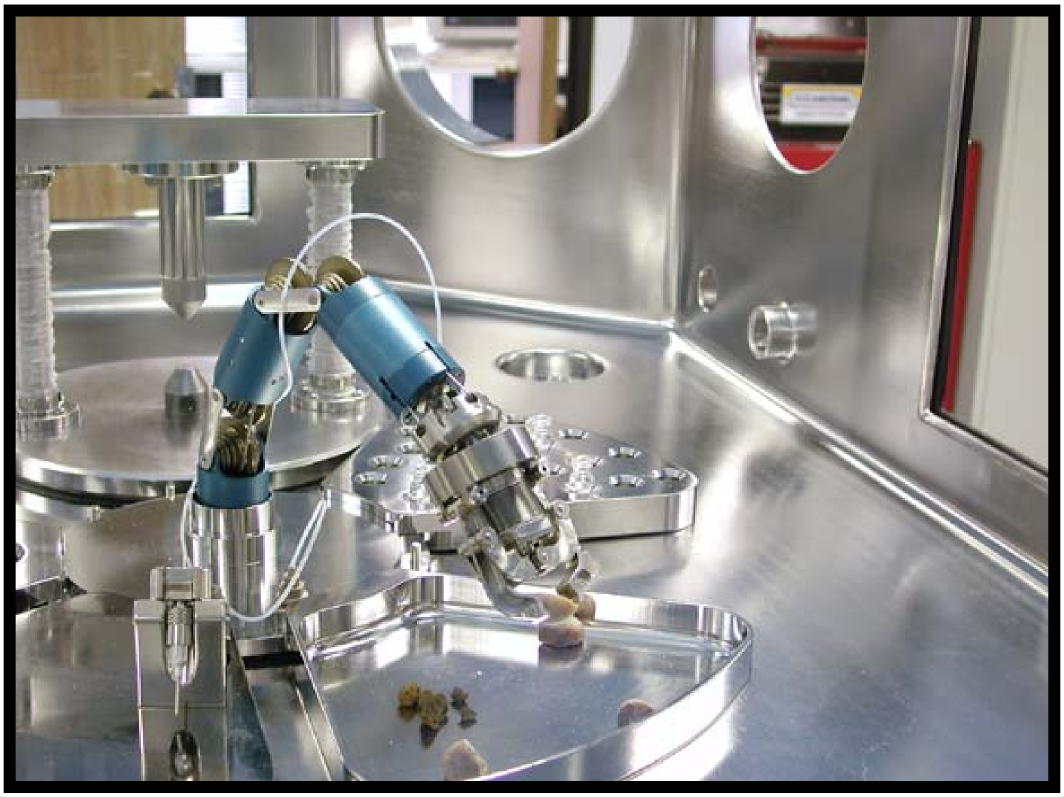
Mars sample return concept

NASA's Mars Exploration Program will eventually include robotic sample acquisition missions to return samples to Earth for detailed study, probably sometime in the next decade. The Astromaterials Acquisition and Curation Office is working to prepare for all of the activities to be done once the sample-containing spacecraft returns to Earth, ranging from recovery of the spacecraft to ultimate distribution of samples to scientists for study.

One of the strong scientific reasons for returning samples from Mars is to search for evidence of current or past life in the samples. Because of the remote possibility that the samples may contain life forms that are hazardous to the terrestrial biosphere, NASA's Planetary Protection Officer (guided by a National Research Council study) has specified that all samples returned from Mars must be kept under strict biological containment until tests show that they can safely be released to other laboratories. It is also important to ensure that scarce or subtle traces of Martian life not be overwhelmed by contamination from terrestrial microbes. Thus, the facilities used to contain, process, and analyze the samples must maintain standards of biological and chemical cleanliness that are unprecedented in high-level biocontainment facilities.

In planning for the processing of Mars samples, the ARES curation staff is building on its experience in preliminary characterization, hazard testing, and distribution of lunar, meteorite, and cosmic dust samples to scientists worldwide. Unique requirements for the processing of Mars samples have inspired an active program to develop sample handling techniques that are much more precise and more reliable than the approach (currently used for lunar samples) of using human hands in nitrogen-filled glove boxes. Individual samples from Mars are expected to be much smaller than lunar samples, the total mass of samples returned by each mission being 0.5-1 kg, compared with many tens of kg of lunar samples returned by each of the six Apollo missions. Smaller samples require much more processing to be done under microscopic observation. In addition, the requirements for cleanliness and high-level containment would be difficult to satisfy while using traditional glove boxes.

JSC has constructed a laboratory to test concepts and technologies important to future sample curation. The Advanced Curation Laboratory includes a new-generation glovebox equipped with a robotic arm to evaluate the usability of robotic and teleoperated systems to perform curatorial tasks. The laboratory also contains equipment for precision cleaning and the measurement of trace organic contamination.



Robotic arm in glovebox

Human Exploration Science Office (SX)

Wendell W. Mendell, Ph.D., Manager
http://ares.jsc.nasa.gov/HumanExplore/intro.html

The Human Exploration Science Office conducts Earth and space science research, planning, and support for human space flight. The office includes several distinct groups, having very different technical responsibilities.

The planetary exploration group focuses on the science to be done during future human exploration of the Moon, Mars, or asteroids. They represent the science "customer" in mission planning exercises. Their work involves planning and modeling geologic and biologic investigations as well providing input to forums on space policy.

The Earth science group manages the database of astronaut images of Earth, trains and debriefs astronauts on geology-geography, conducts Earth science research, and shares this information with the public through their award-winning web site. The image science group analyzes Shuttle and International Space Station mission imagery and researches all anomalies. They have resolved issues raised during missions and have provided data on the state of the Hubble Space Telescope.

The space debris function involves two separate groups. Members of the orbital debris team are some of the world's top experts in modeling and monitoring debris in Earth orbit. They construct complex mathematical models for describing and predicting the debris environment in Earth orbit. The hypervelocity impact test facility team designs and assesses debris shielding for spacecraft. They also use environmental models to evaluate risks to spacecraft, including the Space Shuttle and the International Space Station.

Reports on several projects are given in the following pages.

High Resolution Earth Observations from the ISS

Cynthia Evans, Julie Robinson, Greg Byrne, Kim Willis, Sue Runco, and Kamlesh Lulla

Recently the International Space Station (ISS) Earth Observations program achieved a benchmark —astronauts and cosmonauts aboard the ISS have acquired 100,000 images of the Earth since the first expedition on the station began in November 2000. The Earth Observations Program has realized several important developments in capability, and the rich collection of imagery underscores the versatility of the ISS as an observational platform and the ingenuity of humans in space to provide unique and valuable observations of the Earth. Our key developments include the following:

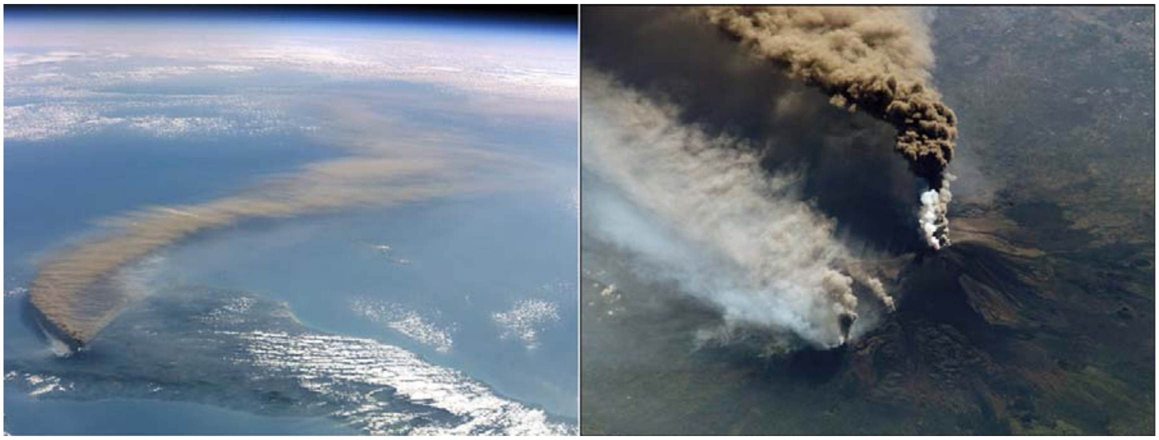
1. Operational use of high quality digital cameras for Earth observations has expanded our ability to respond to dynamic events.

ISS crewmembers are trained to observe and document dynamic events on the Earth's surface, such as hurricanes, forest fires, and volcanic eruptions. Real-time communications with crewmembers about current events and rapid downlink of imagery have provided scientists and the general public a unique perspective on these events. The versatility and operational flexibility of the human observer to notice and frame significant events, and manipulate the equipment (for example, changing camera lenses) to collect complementary data is illustrated below.

Hurricane Isabel
ISS007-E-14887, ESC with a 50 mm lens, 15 September 2003, 10:54 UTC.
ISS007-E-14745, ESC with 180mm lens, 13 September 2003 at 11:18 UTC

This pair of images shows the broad context of Hurricane Isabel and the structure of Isabel's eyewall. At the time, Isabel was located about 725 km northeast of Puerto Rico, heading for the

U.S. coast and was a Category 4 hurricane, packing winds of 240 km/hr. No other sensor images the eyewalls of hurricane with such detail, providing data for three-dimensional studies of the eyewall structure. The National Hurricane Center, NOAA, and many media organizations used these images.

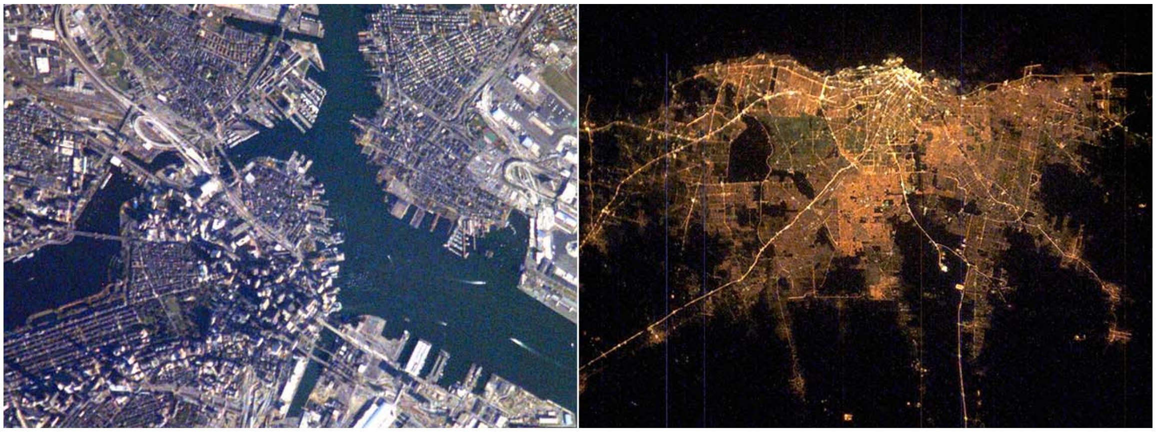


Mt. Etna eruption
ISS005-E-19016, 30 October 2002, 112 mm lens
ISS005-E-19024, 30 October 2002, 800 mm lens

On October 27, 2002, Mount Etna (on the island of Sicily) began its most vigorous eruption in years. The wide, southeast-looking view uses an oblique look angle to show the regional context of the ash plume trajectory. Lower levels of the plume (about 9000 m above sea level) were steered by winds blowing to the southeast. At higher altitudes the plume was carried to the south toward Africa (on the horizon in the upper right). Ashfall was reported in Libya, more than 560 km away. By using a higher-magnification lens, the astronaut was able to capture a detailed image of the eruption plume a few seconds later, showing its vertical profile. Lighter colored plumes down slope of the summit are produced by a line of vents on the mountain's north flank. Images taken by astronauts of large eruptions have been used in joint studies by the USGS and the FAA to help define the volcanic hazards posed to aircraft and air routes.

2. Astronauts on long-duration ISS missions have mastered the use of long lenses (effective 800 mm focal lengths) and using ingenious techniques for motion compensation routinely acquire high-resolution images.

Under normal operating conditions, the cameras used for Earth Observations record movement of the ground as the Earth passes beneath the ISS at approximately 7 km/sec. By learning to track with that motion, astronauts can effectively eliminate the ground smear, producing images with resolutions in the range of 5-6 m. These images can be analyzed as stand-alone data or combined with data from other sensors. A particularly successful campaign of observations has been the collection of high-resolution images of cities from around the world. Not only are these images of great interest to the public, but the imagery provides high fidelity data to combine with imagery from other sensors for applications such as urban mapping (see the image of Boston).



Details of downtown Boston and Buenos Aires at night.
ISS007-E-17770, 20 October 2003, 800 mm lens
ISS006-E-24987, 8 February 2003, 58mm lens

Also, astronauts have innovated new devices to increase the resolution of their images. ISS Increment 6 Science Officer, Don Pettit, pioneered an approach using a home-made tracking system to track the ground as it moves relative to the Station, allowing him to acquire long-exposure images under low light conditions using very long exposures. Don's ingenious "Barn-Door Tracker" is a camera mount rigged with a hand drill to create a motion tracking system (see http://science.nasa.gov/ppod/y2003/10apr_barndoor.htm). The right hand image shows the lights of Argentina's capital city, Buenos Aires. The different colors (pink, white, and gray) define different types and generations of streetlights. This level of detail for city lights at night (about 30 m/pixel) is unique to human spaceflight. Only a few satellites, such as the Defense Meteorological Satellite Program (DMSP) are able to capture night imagery of cities, and these have a much coarser spatial resolution (500 m – 1 km/pixel).

3. Astronauts exploit their observational vantage point to obtain unique sets of imagery that are not acquired by other satellite sensors.

Noctilucent Clouds and Aurora
ISS007-E-10974, 27 July 2003, 400 mm lens, taken over Mongolia
ISS003-E-6152, 4 October 2001, Aurora Borealis

Humans onboard the ISS have the opportunity to observe multiple twilights per day while looking at the horizon, and a unique ability to document the entire atmospheric profile in detail, including the occurrence of noctilucent clouds and auroras. On the left, the sliver of the setting Moon and clouds that shine at night—noctilucent clouds—caught the astronaut's eye as he was flying over Mongolia. Noctilucent clouds are so high (75-90 km) and so optically thin they can only be observed during twilight hours, when the Sun is just below the horizon and only shines on the uppermost atmosphere in summer at latitudes above 50 deg. In this image, the troposphere (lower atmosphere where the Earth's weather occurs) is the dark region at the bottom. The tropopause, the sharp density transition visualized by the orange-blue boundary is at roughly 18 km altitude. Above this boundary (blue) is the stratosphere. The top of the blue area where the noctilucent clouds occur is 90-100 km. Some scientists believe these frequency of occurrence of the elusive clouds has increased during the last century and may be related to global warming. ISS astronauts have observed the distributions of noctilucent clouds over both polar regions.

Astronauts also exploit their unique vantage point to document auroral activity from above, profiling the vertical structure of auroras. On the right image, green colors of the Aurora Borealis over Canada are dominant. Auroras are caused when high-energy electrons pour down from the Earth's magnetosphere and collide with atoms. Green aurora occurs when excited oxygen atoms return to their original state. By using a digital camera with a long exposure time, astronauts can capture a part of the light from the multicolored displays they observe, and downlink those images to Earth.

4. The general public enjoys unprecedented access of ISS Earth Observations results.
The Gateway to Astronaut Photography website (http://eol.jsc.nasa.gov) currently receives 15 million hits/month with more than 500,000 images downloaded monthly. High-resolution images of current events and cities are most popular. Our goal is to provide easy access to the global community of all images of Earth taken from human exploration space flights. Recent database and web server developments have allowed us to serve complete metadata and image access, sophisticated image searches, downloadable high-resolution images, and special image collections to the community of students, teachers, researchers, and the general public. Our images and web sites are crosslinked to other NASA web sites, allowing us to better profile human spaceflight achievements in remote sensing and Earth observations to a wide range of audiences.

A major milestone was reached during 2001 with the long awaited start of Crew Earth Observations from the International Space Station (ISS). This heralded a new era for ARES Earth Science Group, whose missions are to provide astronaut images of Earth for a broad range of science, commercial, and outreach applications and to engage the public in the excitement of human exploration of Earth from space.

Lake Sarez (top), deep in the Pamir mountains of Tajikistan.

Thousands of images were returned from ISS, catalogued, and made available to the public over the web (http://eol.jsc.nasa.gov), adding to our database of over 400,000 Earth images from the Space Shuttle. The public's enormous and growing appetite for the images was demonstrated by our web metrics for the year. By the end of 2001, over one million web hits per month were logged; but that number had increased by an order of magnitude by the end of 2003. At that time, web hits were being recorded from 90 countries, and over 500,000 images were downloaded each month. About one-fourth of all hits were from .com or .edu domains.

One remarkable early finding is the high-spatial resolution of about 6 m achieved in ISS images found by our Earth sciences staff, a significant improvement over previous astronaut imagery and approaching the highest resolution of color images available from commercial satellites. Also, the ISS and Space Shuttle images are now routinely digitized as 3-band color data and georeferenced for scientific analysis. In doing so recently, we demonstrated that astronaut-acquired imagery compares favorably with Landsat data for remote sensing classifications in land-use and vegetation. These new developments enhance the image database as a research resource for both primary data on the state of the Earth and for secondary data to supplement remote sensing information from other sources.

While a new chapter for Earth Observations was opened with the start of ISS operations, the chapter on its successful predecessor, Shuttle-Mir Earth Observations, was closed with the publication of a compilation of the Shuttle-Mir Earth science results. Also, the Earth Sciences staff was active in outreach activities, highlighted by regular submissions to NASA's popular *Earth Observatory* web site (http://earthobservatory.nasa.gov).

The decline in health of coral reefs worldwide has gained international attention, and the Earth Sciences staff is deeply involved with research into this global problem. We are applying Shuttle and ISS images of coral reefs in conjunction with Landsat data for discriminating between clouds and reef structure; an important process for the reef mapping. The staff also contributed images and consultation to a 2001 United Nations publication, World Atlas of Coral Reefs. In addition, a staff proposal "Using Landsat 7 Data in a GIS-based revision of ReefBase (A Global Database on Coral Reefs and Their Resources)" was selected for funding by NASA Headquarters (Code Y).

Thunderstorms with glaciated anvil tops

During 2001, the Earth Sciences staff completed a heavy load of astronaut crew “Earth smart” training. The training highlighted scientific themes, such as human impact on the environment, global change in climate, health of coral reefs worldwide, changes in ice packs and glaciers, changes in river deltas, and accumulations of atmospheric aerosols. Upgrades to the Earth Observations Lab continue to strengthen operations. Two important mission support upgrades were completed: configuration of the Earth Science console in the Mission Control, Telescience Support Center, and implementation of the Satellite Tool Kit’s state vector propagation software for STS and ISS tracking, the latter resulting in more accurate orbit timing for the Earth photo targets identified in the uplink flight notes to the crews. Operations for ISS are currently progressing smoothly.

The compact Italian city of Venice with its renowned canals.

Measurements of the Orbital Debris Environment

Eugene G. Stansbery

Orbital debris is a concern for all present and future space-faring nations. The U.S. Space Command tracks orbiting objects larger than about 10 cm in diameter. Objects much smaller than this size still can damage operational spacecraft because of the high relative velocities between orbiting objects (average collision velocity = 10 km/s). The Orbital Debris Program Office measures the debris environment in a statistical sense for objects smaller than 10 cm that cannot be tracked.

Radar Measurements

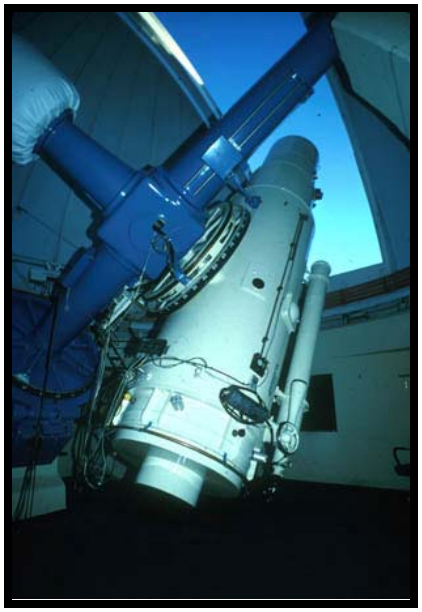
NASA has used the Haystack Observatory, including both the Haystack and HAX radars, since 1990 to sample the debris environment at low Earth orbit (LEO) altitudes. The Haystack radar is a high power, X-band (3-cm wavelength) radar with very high sensitivity. It is capable of detecting debris as small as 0.5 cm diameter at an altitude of 500 km. HAX can detect 2 cm diameter debris at 500 km but has a larger field of view. Rather than tracking individual objects, these radars are used in a non-tracking, or “staring,” mode which allows debris to pass through the radar’s field of view. The rate at which objects are detected can then be related to the density or flux of particles in orbit. NASA collects 600 hours of data from each of the two radars each year.

The Haystack (large dome) and Haystack Auxiliary (HAX) Radar (small dome) located in Tyngsboro, Massachusetts, northwest of Boston.

Optical Measurements in GEO

From 1995 to 2001, NASA/JSC operated a 0.3-m telescope located in Cloudcroft, NM, to conduct searches for high altitude debris in the region of geostationary orbit (GEO). Within the next several years, NASA plans to deploy a 1-m telescope in the Pacific to conduct similar research (see next section). In the interim, a cooperative program with the University of Michigan provides measurements of this important and highly populated orbital regime.

NASA is collaborating with the University of Michigan operating its 0.6/0.9-m classical Schmidt telescope located at the Cerro Tololo Inter-American Observatory, Chile. The facility is capable of detecting a 10-cm object at GEO, assuming an albedo of 0.2. More than 340 hrs of data were collected in FY2003.



The University of Michigan 0.6/0.9 Schmidt telescope located at the Cerro Tololo Inter-American Observatory in Chile.

Meter-Class Autonomous Telescope (MCAT)

NASA and the Air Force Maui Optical and Supercomputing (AMOS) site are cooperating to place a wide field of view, meter-aperture telescope on Kwajalein Atoll for space debris research. The telescope system, designated the Meter-Class Autonomous Telescope (MCAT), will be deployed as part of the High Accuracy Network Orbit Determination System (HANDS) and will use the Oceanit, Inc., K-Star design.

The telescope will operate in two different modes. During twilight hours it will sample low inclination orbits in a “track before detect” mode. In the middle of the night it will perform a more standard GEO search. Kwajalein Atoll was chosen as the location for MCAT because: 1) its low latitude location is necessary for sampling low inclination orbits, 2) its location allows it to measure a part of the GEO belt not covered by other optical sensors, and 3) it has a technically skilled workforce that can help maintain the telescope.

Spectroscopic Observations of Space Debris

Kira Jorgensen

When most people think of orbiting objects, intact, operating satellites come to mind. In addition to these operating satellites, there are approximately 10,000 objects in low Earth orbit (LEO) that are larger than 10 cm in diameter and a very much higher number of objects smaller than 10 cm. We can better characterize the space environment if we can determine the physical characteristics of orbiting objects. These properties are used in current space environment models and in designing shields for spacecraft, as well as in providing basic information for predicting the future environment. Some of these characteristics, including material type, are currently assumed. We have shown that it is possible to determine material types of man-made orbiting objects in both low Earth orbits (LEO) and geosynchronous Earth orbit (GEO) using low-resolution reflectance spectroscopy, comparing absorption features and overall shape of spectra.

NASS (NASA AMOS Spectral Study) began observations in May 2001 collecting data for eight nights. Since then, data from fifteen additional nights have been collected. Currently, more than 60 rocket bodies (R/Bs) and spacecraft (S/C) spectra have been collected using the 1.6-meter telescope at Air Force Research Laboratory (AFRL) Maui Optical Supercomputing (AMOS) site. The remote spectra were compared to the database of spacecraft material spectra kept at JSC.

Each material type has a different spectrum based on its composition. Figure 1 shows the reflectance spectrum of a LEO R/B (shown in black with more noise) overlaid with a laboratory sample (in red and smoother). The feature near 400 nm is due to white paint. The difference in the wavelength of that feature in the two spectra is due to the difference in temperature between the remote and laboratory sample. Near 840 nm is another dip in the line, a feature due to aluminum. Features like the one from aluminum, unlike the one at 400 nm due to white paint, are harder to distinguish. Thus, we infer that the rocket body is made of aluminum coated with white paint.

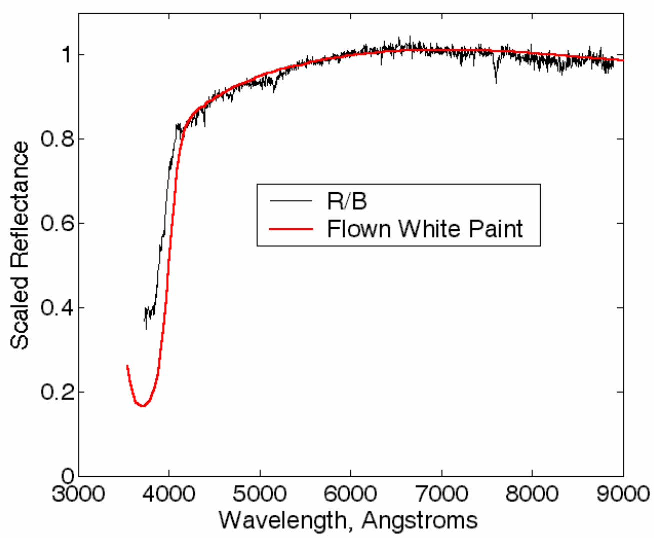


Figure 1: Laboratory Spectrum of White Paint (Red) compared to a remote spectrum of a LEO R/B. The match is very good.

In addition to determining the material type of orbiting objects, NASS can be used to evaluate the degradation of intact satellites. R/Bs with similar paint schemes will exhibit similar spectral features, but the characteristic reflectance can change with exposure to the space environment.

A puzzling observation from the astronomy community highlights the range of possible uses for the spacecraft materials spectral database. An object thought to be an asteroid, J002E3, was observed in September, 2002. Its erratic orbit made astronomers question whether or not it was actually an asteroid. A spectrum, taken at the Infrared Telescope Facility (IRTF) on Mauna Kea, was sent to JSC to see if the spectrum would match human-made materials. Assuming the object might be an upper stage, a model was developed from its known dimensions and paint scheme. The variation between the two models is seen in the kind of white paint used, as seen in Figure 2. This object was concluded to be 60% white paint that has turned gold in color due to space environment exposure with the remaining materials being 10% black and 10% yellow paint and 20% exposed metals.

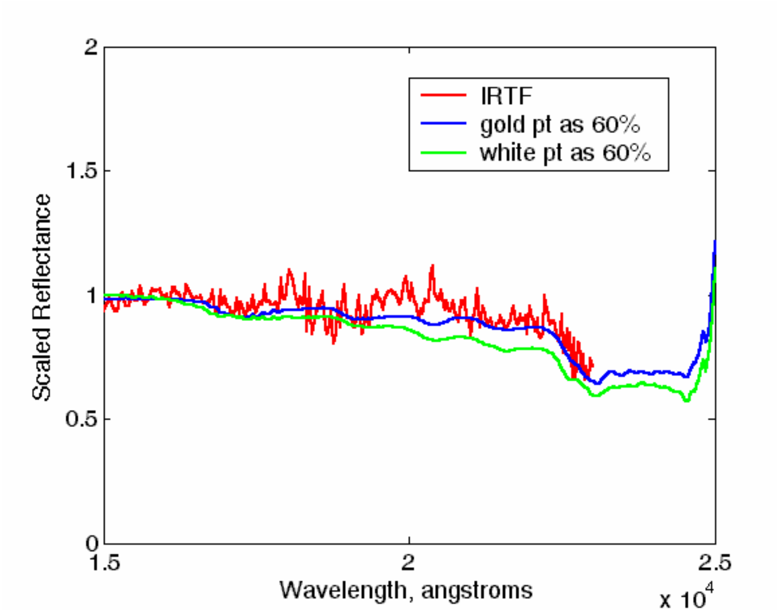


Figure 2: IRTF spectrum of J002E3 (in red) as compared with two models of possible paint schemes depending on the kind of white paint used. The comparison shows a good correlation near 1.7 and 2.3 microns where the C-H bands of white paint are seen.

More observations are scheduled using the 1.6-meter telescope at AMOS as well as with the 3.67-meter telescope at the same site. As more observations of R/Bs, intact satellites, large debris fragments, and eventually, smaller debris are accumulated, it will be possible to determine whether the effects of space weathering and other age-dependent factors can be reliably measured with this technique.

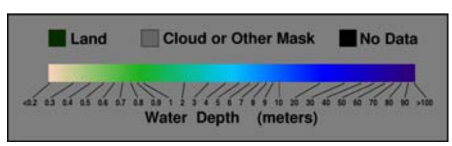
Using Landsat 7 Data in a GIS-based Revision of ReefBase: Distributing Information on Land Cover and Shallow Reefs to Resource Managers

Julie A. Robinson, Serge Andréfouët, Gene Feldman, Rick Stumpf, Jennifer Gebelein, Ed Green, Marco Noordeloos,and Lauretta Burke

Coral reefs are an important part of the economies of many developing countries in the tropics, and are estimated to provide all the dietary protein for over 500 million people worldwide. They are important sources of food production, and major centers of marine biodiversity. Coral reefs are also some of the most threatened ecosystems in the world due to combined effects of overexploitation, pollution, and global climate change. Recent risk analysis suggests that up to 30% of coral reefs may have been irreversibly damaged, and an additional 30% are under significant threat. However, analyses are limited by the poor quality of existing global reef maps—estimates of the existing area of global coral reefs range from 284,000 km^2 to 3.9 million km^2!

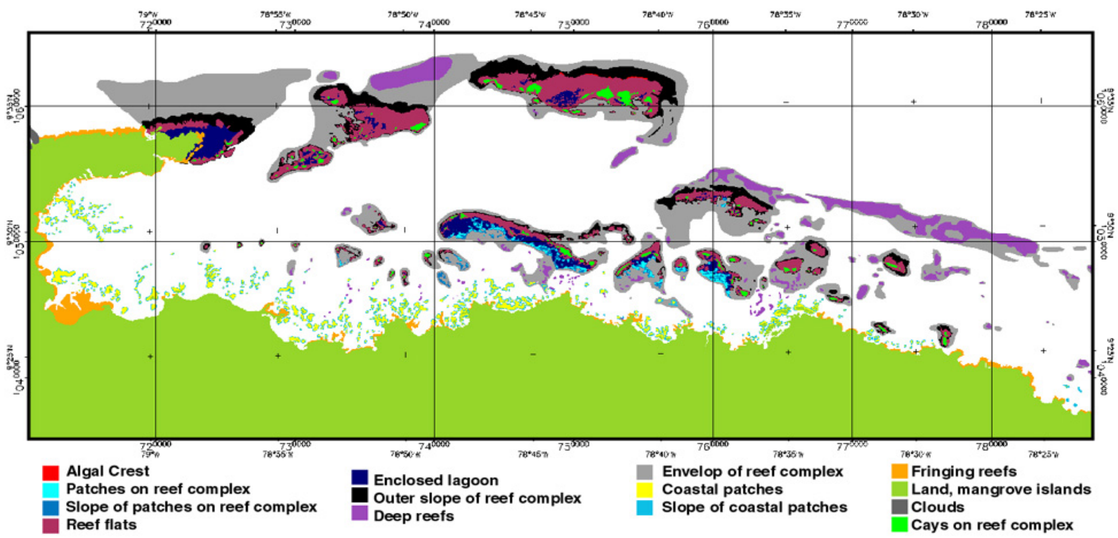
NASA's Earth Science Enterprise has supported a 3-year project led by JSC to facilitate the use of Landsat 7 data for improving map quality in global coral reef datasets. The effort is designed to extend the users of remote sensing data beyond to research community to those doing applied resource management. Partners in the project include the Institute for Marine Remote Sensing, University of South Florida, Florida International University, Goddard Spaceflight Center, the United Nations Monitoring Programme-World Conservation Monitoring Centre (WCMC), and the World Fish Center, World Resources Institute, and NOAA National Ocean Service.

Objective 1: Improve existing global coral reef maps. Currently only 30% of the worlds' reefs are mapped at a 1:250,000 scale or better, and the existing global map was compiled from nautical charts with a variety of scales and accuracies by WCMC. Through collaboration between NOAA and NASA SeaWiFS, a method was developed to produce a global 1-km spatial resolution shallow water bathymetry map. This map employed the high positional accuracy of SeaWiFS to produce a cloud-free composite and allowed immediate correction of positional errors in the WCMC map.



This Map of Kiritimati shows the SeaWiFS composite global bathymetry map. The red line shows the existing WCMC reef map, which is in the wrong position. The corrected position is shown in yellow.

A global scheme for uniformly classifying the geomorphological structures of reefs using Landsat 7 data has been developed. Over 900 Landsat 7 scenes were obtained, and the mapping protocols are being applied to produce the first uniform global coral reef map at 30 m resolution. Map production is being coordinated on 3 continents, and including participation by end-users such as WCMC. The "Millenium Coral Reef" geomorphological map will provide the most accurate estimate of shallow reef ecosystems to date, with extensive information on reef features that will be useful to scientists and managers. The maps will be complete by June 2004.



New "Millenium Coral Reef Map" from Landsat 7 data of Nargana, Kuna Yala (San Blas) archipelago, Caribbean Panama, showing coral reef types and distribution, and geomorphology-biodiversity relationships.

Objective 2: Distribute data and maps to scientists and reef managers. Through the World Fish Center's ReefBase project, maps and accompanying data will be provided to the world in an interactive on-line geographic information system (GIS) tool. ReefBase integrates data from dive surveys, NOAA studies of coral bleaching potential, and other data sources into one single location. All their resources are distributed free of charge. They also produce custom regional products for free for use in developing countries where Internet access is limited. The first set of new reef maps has been incorporated into ReefBase as a test set. Maps will then be added in bulk when the global mapping is complete.

Many of the specific mapping needs of local managers cannot be accommodated by the global mapping project. Instead, the more than 900 Landsat 7 scenes that were assembled for this project will be incorporated into an online archive. These data will be available for free downloading by the research and management community for use in custom mapping applications. The prototype search interface is complete, and data are currently being standardized for inclusion in the archive.

Objective 3: Improve the integration of land cover data with studies of nearby reefs. The World Resources Institute (WRI) has been the leader in developing reef risk assessment models that incorporate land, reef, and human impact data. They are currently completing a detailed regional "Reefs at Risk" analysis for the Caribbean. Although previous risk assessments used coarse 1-km data, this is not suitable for the many small islands of the Caribbean. In collaboration with WRI, we have developed Landsat-7 based land cover maps and accompanying coral reef maps for the Greater and Lesser Antilles, allowing the risk assessment to be completed with 30-m data. We are also cooperating to assess the effect that spatial resolution and land mapping techniques have on the results of risk assessments, so that the procedures can be improved for future regional analyses. The Caribbean Reefs at Risk Assessment will be completed in early 2004, and the next effort will be for the Pacific.

The results of all of these collaborations will be presented at a special hallmark symposium on integration of remote sensing data and mapping into coral reef management applications to be held at International Society for Reefs Studies Meeting in Okinawa, June 2004. Through Earth Science Enterprise Applications support, we have been able to find common goals and synergies between the many different coral reef mapping and assessment activities, increase the value of the mapping products, and significantly broaden the availability of the information.

The Evolution of the Earth's Satellite Population

Nicholas L Johnson

Since the beginning of the Space Age, more than 4300 missions from around the world have placed man-made objects into orbit about the Earth. Although the majority of these objects, primarily spacecraft and launch vehicle upper stages, have already fallen back to Earth, the number of objects in Earth orbit continues to grow at a steady pace. In addition to the placement of new vehicles into orbit, a significant portion (~40%) of the official worldwide satellite catalog is comprised of debris from spacecraft and launch vehicle explosions. A collision with any of these cataloged objects could result in the destruction of an operational spacecraft.

Orbital debris research in ARES includes the investigation of potential trends of the Earth's satellite population into both the near-term and the far-term, i.e., within the next few decades and over periods of hundreds of years. This research is vital to evaluating the efficacy of proposed orbital debris mitigation measures. In the 1980's the Orbital Debris Program Office identified the prevention of launch vehicle upper stage explosions as the best means to curtail the near-term growth of orbital debris. Subsequently, all the major space agencies of the world revised launch vehicle designs or operations.

Complex computer models are used extensively to aid in understanding the principal drivers of the future Earth satellite population. In 2003, a multi-year effort within ARES culminated in a new NASA satellite evolutionary model called LEGEND (LEO-to-GEO Environment Debris model). The model has already confirmed previous analyses that the long-term Earth orbital environment will likely be driven by the accidental collisions of large (>10-cm diameter) objects. Consequently, the accelerated removal of large objects from orbit is a vital element in environment preservation efforts. Such analyses have led NASA and the international aerospace community to adopt guidelines recommending the removal of objects within 2000 km of the Earth's surface from orbit within 25 years of the end of their missions. LEGEND represents a new, high fidelity tool to examine these and other factors affecting the near-Earth environment and the future safety of operational spacecraft.

International Guidelines for the Mitigation of Orbital Debris

Nicholas L. Johnson

Significant strides aimed at curtailing the growth of the artificial debris population in orbit about the Earth were made during 2002-2003. Since the launch of Sputnik 1 in 1957, worldwide space activity has led to the creation of millions of man-made objects in near-Earth orbits. Less than 5% of the more than 13,000 objects tracked by the U.S. Space Surveillance Network are operational spacecraft, the rest being non-functional spacecraft, expended launch vehicle stages, mission-related hardware, and fragments from on-orbit explosions.

For nearly 25 years, NASA's Orbital Debris Program Office has led national and international efforts first to understand and to define the orbital debris environment and then to mitigate the growth of the orbital debris population. In 2003 NASA revised its policy directive on preventing the creation of orbital debris, and the subsequent directive, NPD 8710.3A, greatly expanded the role and responsibilities of the Orbital Debris Program Office.

NASA was the first space agency in the world to establish detailed guidelines for orbital debris mitigation. In 1997 U.S. Government Orbital Debris Mitigation Standard Practices were developed, based upon the NASA guidelines, for all U.S. government agencies developing and operating satellites in Earth orbit. Concurrently, foreign space agencies began developing their own orbital debris mitigation guidelines, again based in large measure on those of NASA.

During the Second World Space Congress held in Houston in October 2002, the Inter-Agency Space Debris Coordination Committee (IADC), comprised of the space agencies of ten countries as well as the European Space Agency, completed a multi-effort to develop an international set of orbital debris mitigation guidelines. ARES orbital debris experts played critical roles in this accomplishment. In February 2003 the IADC guidelines were formally presented to the

Scientific and Technical Subcommittee of the United Nations’ Committee on the Peaceful Uses of Outer Space.

In 2002 and again in 2003 ARES personnel, representing the entire United States, made presentations on orbital debris mitigation before the United Nations. These same personnel are members of a U.S. Government interagency working group striving to promote the responsible use and protection of the near-Earth environment by all space-faring nations and organizations.

Impact Testing of the Orbiter Thermal Protection System

Justin Kerr

Ascent video and photography captured during the STS-107 mission showed debris from the external tank (ET) striking the Orbiter Columbia’s lower left wing 82 seconds after launch (T+82) of the STS-107 mission. During the mission, photo analysis teams, led by the Image Analysis Group in ARES, estimated an upper limit of approximately 50 cm for the size of the debris liberated, with an uncertainty of plus or minus 25 cm. The visual evidence implicated the ET left bipod ramp as the source of the debris. Calculations of the debris velocity at impact ranged from 190 m/s to 256 m/sdepending on the various methods and assumptions used, with the most probable velocity estimated to be approximately 200m/s.

NASA and the Columbia Accident Investigation Board (CAIB) considered the T+82 impact a likely initiating event of the accident; thus it required further evaluation. To replicate the impact, the Orbiter Vehicle Engineering Office chartered an Orbiter Thermal Protection (TPS) Impact Test Team. The scope of the task included design and construction of test article hardware, modification of facilities to conduct the tests, and detailed planning of test parameters. The impact test program was conducted in close coordination with the CAIB and was led by the Hypervelocity Impact Group of ARES.

Test Program Summary

Because the impact occurred on the lower left wing of the Orbiter *Columbia*, test articles were envisioned for unique areas on its surface: wing acreage tile and structure, the main landing gear door (MLGD), and the leading edge. The materials in these areas would have differing reactions to an impact by foam debris; likewise, a breach in these areas would yield varying Orbiter system responses during reentry plume impingement. By the time testing began, the investigation teams had determined that the debris impacted the lower leading edge between panels 8L and 9L.

Engineers utilized the unique capabilities of the Southwest Research Institute to conduct the tests. Figure 1 shows the test range at the Institute. The foam projectiles were launched to velocity using a large compressed-gas gun. The outdoor test site included a stand on which to mount targets and a 8-meter-tall curtain to catch ejected debris. As many as 13 high-speed video cameras were used to image the projectile flight path and the impact event itself. Engineers used the data from these images to determine the projectile velocity and orientation at impact as well as the detailed motion and potential failure of the target after foam impact. The targets were equipped with strain gages, accelerometers, and deflection gages that enabled engineers to measure the strains in the TPS and the underlying Orbiter structure. Up to 275 channels of instrumentation data were collected during each test.

To prepare for the leading edge test program, five tests were conducted on LI-900 TPS tiles bonded to a left MLGD. These tests were used to evaluate the response of tile impacted by foam at representative velocities and angles and to verify test facility, instrumentation, and high-speed camera readiness. BX 250 foam at sizes (14000, 20000, 30000 cm^3), velocities (200 to 235 m/s feet per second), and impact angles (5 to 13 degrees) representative of the debris were shot at the MLGD with a large compressed-air gun facility at Southwest Research Institute. The results demonstrated very little damage to the tiles for the range of parameters tested. None of the damage could be considered critical.

A leading edge test article of representative structural response was manufactured to enable impact testing of reinforced carbon-carbon (RCC) panels, RCC T-seals, and TPS tile carrier

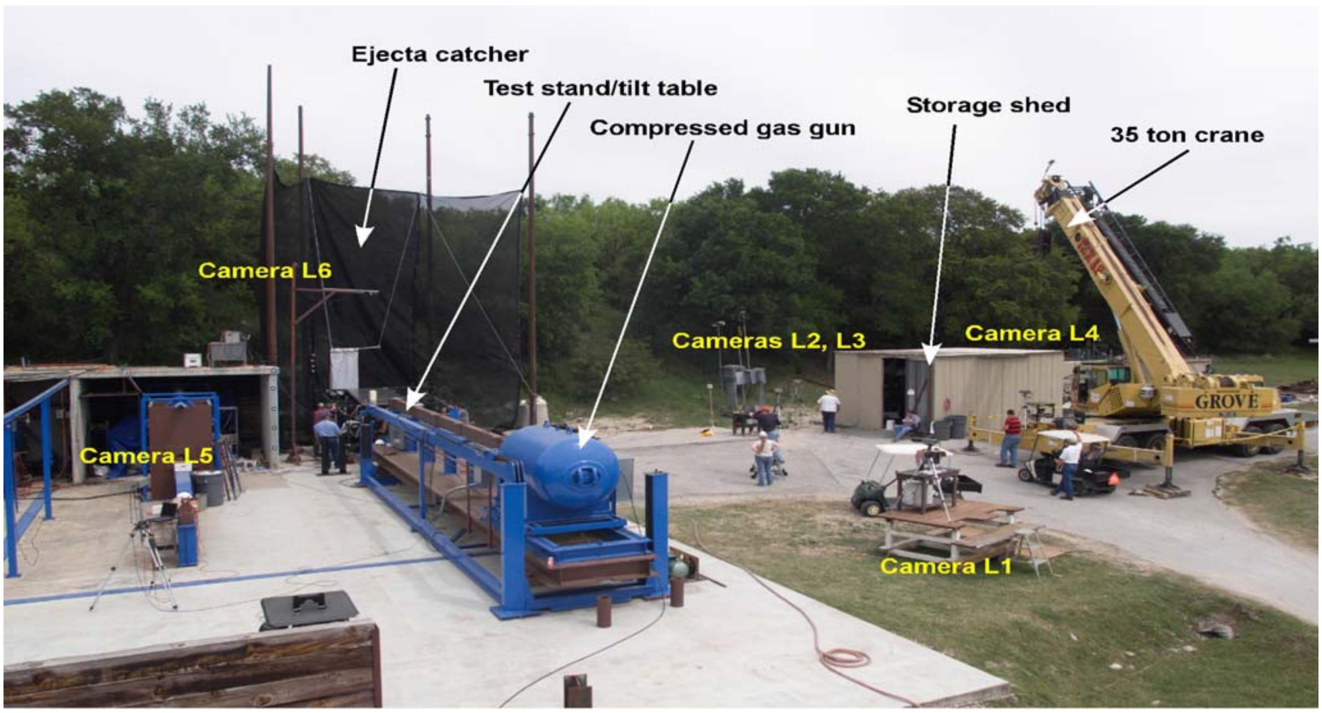


Figure 1. The Orbiter TPS impact test site at the Southwest Research Institute.

panels. Of priority were tests on the RCC components. Due to the scarcity of available RCC flight panels, analysis techniques and impact tests on fiberglass panels of outer mold line geometry identical to that of the RCC panels were used to optimize the test conditions for each RCC test. Two RCC panel tests were ultimately conducted, one each on panels 6L and 8L. In total, five tests were conducted on fiberglass panels.

For the panel 6L test, a 20000-cm^3 BX 250 foam projectile impacted the panel at a velocity of 234 m/s. A lower corner of the foam block first impacted the panel near the slip-side rib. Figure 2 shows the largest through crack on panel 6L post-test. The crack, measuring approximately 14 cm inches, traversed the entire rib and lock and 1.9 cm inches onto the lower panel face. In addition, the panel 6L T-seal exhibited a crack 6.4 along its web (Figure 3).

Figure 2. Through crack on lock-side rib of RCC panel 6. The crack propagated across the entire rib, the lock, and onto the lower surface of the panel. The total crack length is 14 cm.

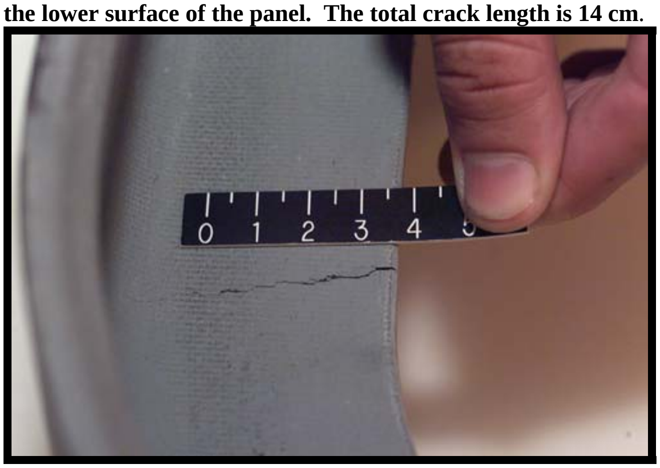


Figure 3. Panel 6 T-seal crack.

The test conducted on panel 8L yielded results that were consistent with estimated damage inferred from onboard sensor data and forensic evidence. A foam block the same mass and approximately the same size as tested for panel 6L was launched to a velocity of 237 m/s The foam block initially impacted the panel several inches closer to the middle of the panel and was clocked at an angle such that most of the leading edge of the block loaded the panel. The foam block produced a hole 41 cm by 42.5 cm inches at the widest point (Figure 4). Cracks were noted along the lock and slip sides of the panel. The panel 8L T-seal was cracked at its lug, opening a slight gap between the panel and the seal (Figure 5). The RCC materials displaced from the panel were found inside the test article (Figure 6). The largest two fragments were approximately 20 cm by 33 cm and 19 cm by 29 cm. Joint scenario testing of TPS materials ended upon completion of this test.

Figure 4. Panel 8L post-test damage.

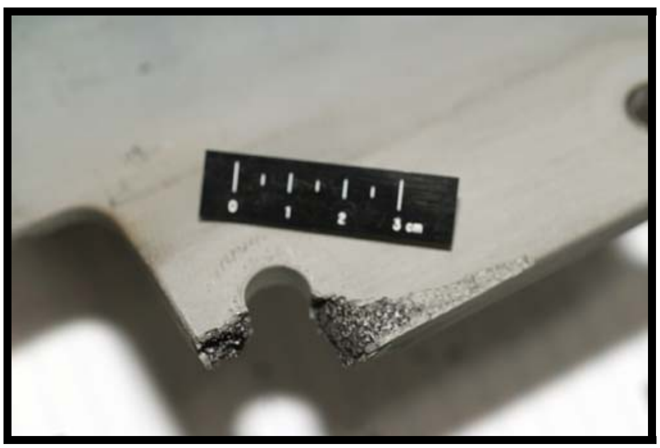


Figure 5. Cracked panel 8L T-seal.

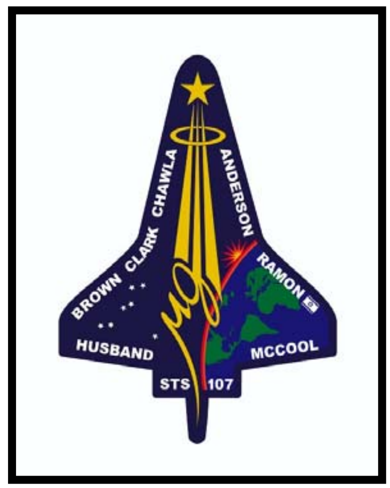
Figure 6. RCC fragments recovered from the inside of the leading edge test article.

For Additional Detail

NASA Technical Publication TP-2003-212066, “Impact Testing of the Orbiter Thermal Protection System: Final Report in Support of the Columbia Accident Investigation,” documents in detail the activities conducted by the Orbiter TPS Impact Test Team for the OVE Office, the NAIT, and the CAIB. The report is divided into six sections: (1) introduction, (2) test facility design and development, (3) test article and projectile fabrication, (4) test program descriptions, (5) results, and (6) future work. The report fully documents the test program development, methodology, results, analysis, and conclusions to the degree that future investigators can reproduce the tests and understand the basis for decisions made during the development of the tests. Furthermore, it will serve to communicate the results of the test program to decision makers, the engineering and scientific communities, and the public.

Imagery Analysis in the Investigation of the Shuttle Columbia Accident

Gregory J. Byrne, Cindy A. Evans, and S. Doug Holland



Analysis of imagery from the STS-107 mission was central to the investigation of the Space Shuttle Columbia accident. The image analyses, led by our Earth Sciences and Image Analysis Laboratory, provided insight into the condition of the Orbiter during the mission and the events leading to its breakup during reentry.

The image processing and analysis tasks for the investigation were numerous and diverse, many involving low quality imagery. In some cases the analyses required problem solving for which there were no established methods. To address these challenges, our Office established the STS-107 Image Analysis Team consisting of resources and expertise from various centers within NASA, as well as from industry and organizations outside of NASA. The Team was responsible for assessing and analyzing all available mission imagery from ascent, orbit, and entry.

The primary sources of imagery for the ascent analysis included launch film and video from tracking cameras located around the launch complex. On-orbit imagery was down-linked during the mission. Entry analysis was accomplished primarily with video and still photos submitted to NASA by the public after the accident. Members of our Office were instrumental in image analyses for all phases of the mission and authored the final report of the Image Analysis Team. Our analyses factored prominently into the investigation by the Columbia Accident Investigation Board (CAIB). The Image Analysis Team final report was referenced in the CAIB Final Report and attached to it as an appendix.

Our focus has now turned to the Shuttle Program Return-to-Flight effort to evaluate and enhance the Shuttle imaging capabilities. In addition to enhancing existing ascent imaging and analysis capabilities, we are developing new capabilities for on-orbit inspection and entry imaging. The result of this effort will be an end-to-end mission imaging and analysis system, improving Shuttle safety of flight.

Advanced Space Propulsion Laboratory (ASPL)

Franklin R. Chang-Díaz, Ph. D., Director
http://spaceflight1.nasa.gov/shuttle/support/researching/aspl

The Advanced Space Propulsion Laboratory was founded in December 1993 and became part of the ARES in 2003. The laboratory is developing a new type of rocket technology, the Variable Specific Impulse Magnetoplasma Rocket (VASIMR), an engine powered by electrical energy that heats plasma to extreme temperatures. Combined with nuclear power, this new technology could dramatically shorten human transit times between planets. The VASIMR would also be able to propel robotic and cargo missions with very large payloads.

The VASIMR system encompasses three linked magnetic cells, consisting of a “plasma source,” an “RF booster,” and a “magnetic nozzle.” With this configuration, plasma can be guided and controlled over a wide range of temperatures and densities. The plasma source cell involves the main injection of neutral gas (typically hydrogen, or other light gases) to be turned into plasma and the ionization subsystem. The RF booster cell acts as an amplifier to further energize the plasma to the desired temperature using electromagnetic waves. The magnetic nozzle cell converts the energy of the plasma into directed motion and ultimately useful thrust.

A unique feature of the VASIMR is its capability to vary or “modulate” the plasma exhaust properties, thrust and exhaust velocity (often referred to, as specific impulse), while maintaining maximum power. As the ship moves away from a planet’s gravity, the thrust is reduced and the specific impulse increases, greatly reducing propellant consumption. The reverse is true as the ship slows down to enter and orbit about its destination planet. The development of VASIMR is the result of joint work by NASA JSC, other NASA centers, two national laboratories, private industry and academia.

Plasma theory and simulation

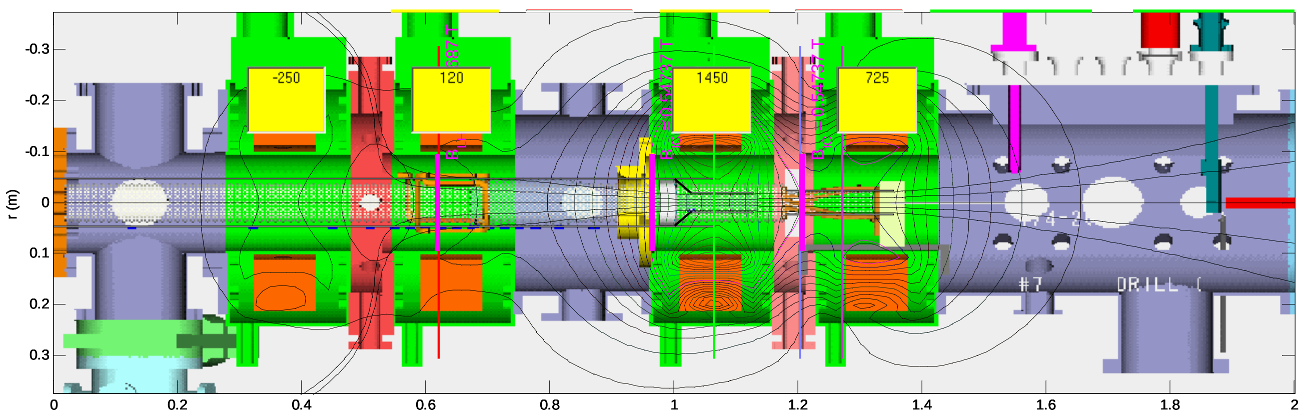
Andrew V. Ilin, Ph. D., Mark D. Carter, Ph. D., Boris N. Breizman, Ph. D., Alexei V. Arefiev, Ph. D., Alfonso G. Tarditi, Ph. D., John V. Shebalin, Ph. D.,and Oleg V. Batishchev, Ph. D.

The successful design of the VASIMR depends on accurate prediction of the system behavior. To accomplish this, extensive use of analytical and computational approaches is made; these include:

- kinetic Vlasov and fluid simulations of the plasma source;
- fluid and particle trajectory simulations of the RF booster cell;
- magneto-hydro-dynamic (MHD) and particle methods for the magnetic nozzle.

Recent advances in the RF booster simulation have incorporated an electromagnetic wave code named EMIR, developed by the Oak Ridge National Laboratory (ORNL) for use in fusion research. With this enhancement, ASPL researches successfully predict booster antenna performance. These predictions have now been experimentally verified. The simulations have enabled the optimization of the antenna design for VASIMR RF booster operations.

The magnetic nozzle simulation has demonstrated the physics of the plasma expansion and acceleration as well as its subsequent detachment from the rocket. The plasma behavior resembles that of solar mass ejections and their interaction with the magnetosphere. Both particle and MHD simulations have predicted that plasma detachment occurs at a distance of about 2 meters from the RF booster antenna in a 10 kW VASIMR device.



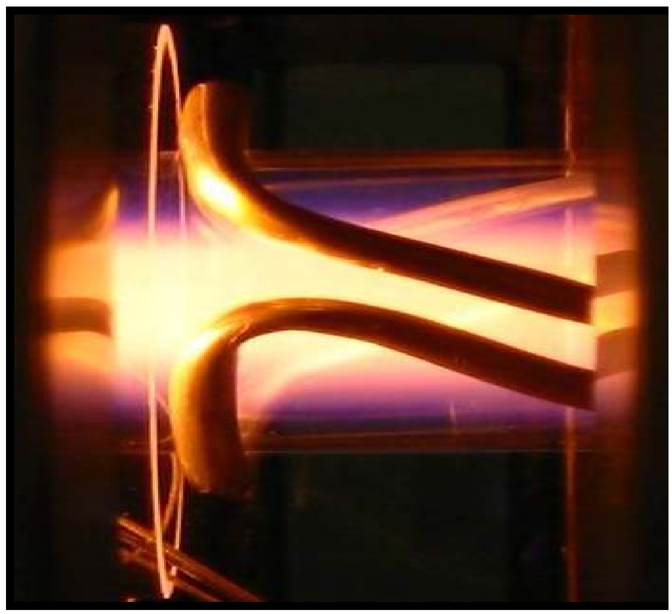
Calculated magnetic field combined with VASIMR experiment drawing

Experimental Research on the Magnetoplasma Rocket

Jared P. Squire, Ph. D., Tim W. Glover, Ph. D., Edgar A. Bering III, Ph. D., Verlin T. Jacobson, Greg E. McCaskill, Jim E. McCoy, Ph. D., Roger D. Bengtson Ph. D., Rick H. Goulding, Ph. D., F. Wally Baity Jr., Ph. D., Pat Colestock, Ph. D., Max Light, Ph. D., and D. Greg Chavers, Ph. D.

Efficient plasma generation, heating and controlled exhaust from the magnetic nozzle are key challenges to the ASPL's experimental effort. By the beginning of 2003, the ASPL research team has achieved expertise in generating plasma with close to 100% ionization rate.

In the second half of 2003, the ASPL completed a very successful experimental effort that demonstrated the physics of the RF booster stage. RF coupling of power to the plasma was precisely characterized and compared to calculations performed by the ORNL collaborators. Agreement between measured and calculated (EMIR code) data is exceptional. With the ion resonance in the proper location, significant ion acceleration is observed. Power balance, based on the coupling measurements and calculations, predicts the measured ion energy very well. These results were presented at the 2003 Annual Meeting of the Division of Plasma Physics of The American Physical Society where they were well accepted by this community.

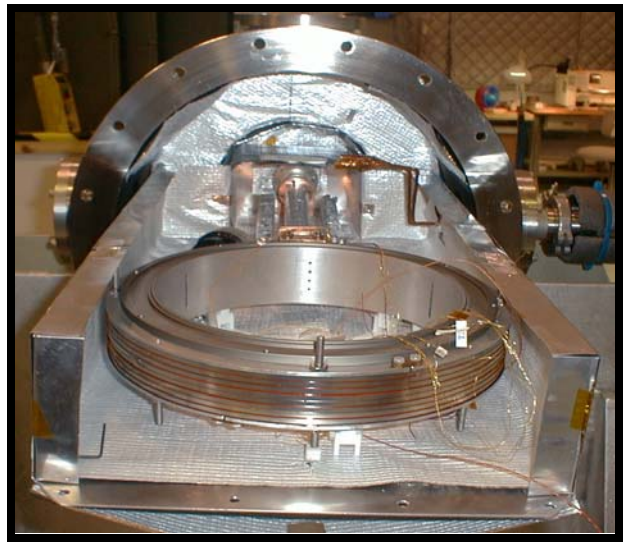


Plasma passing through the RF booster

Similar results using gases other than helium (deuterium and hydrogen) have also been demonstrated. These results have expanded the operational envelope of the engine. A more substantial effect with deuterium has been found that shows promise for future operations. Most significantly, the research team was able to determine ion acceleration from two completely different diagnostics with outstanding agreement. The data indicate that the system is already performing as a rocket with over 10,000 seconds of specific impulse. Also, a potentially more efficient magnetic configuration was identified.

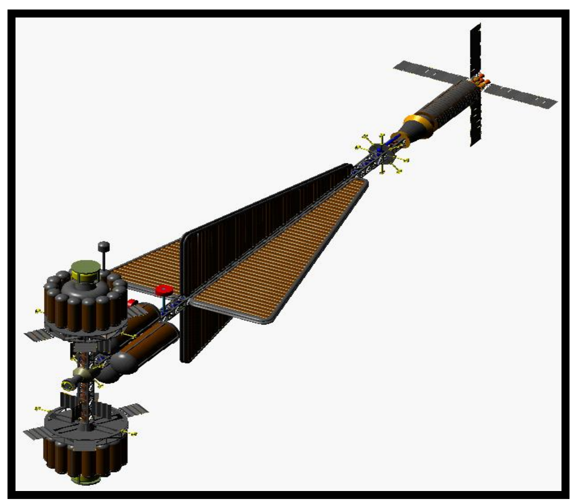
Engineering Activities on VASIMR

Andrew J. Petro, D. Scott Winter, Lee M. Morin, Ph. D., Stephen W. Miller, Laurie W. Carrillo, and Jesus G. Vera



Superconducting magnet installed in test chamber

During 2003, the ASPL made progress in several areas of engineering development. The first high-temperature superconducting magnet was assembled in a special test chamber, cooled to 40K and operated with power to generate the expected magnetic field. Compared to conventional copper electromagnets, superconducting magnets offer dramatic reductions in mass and power consumption and will be employed in future versions of the rocket engine. An even more innovative magnet design was developed under a phase 1 SBIR contract with Tai-Yang Research, Inc. A phase 2 contract was awarded for fabrication of this magnet design in the coming year.



Langley Research Center concept for deep space mission employing VASIMR propulsion

Extensive thermal data were collected and analyzed to better understand the performance of the current rocket experiment. Thermocouple devices were installed within the device through several iterations and the data were evaluated to determine locations of peak heating and overall heat deposition. No major problems were identified but as with any propulsion device, proper thermal management will be an important challenge in the rocket design.

A new type of RF booster antenna was designed and fabricated for testing in the rocket experiment. This antenna was constructed from copper tubing, installed in the chamber and operated successfully. Cooling was not provided for this initial antenna but its design will support water-cooling in the future.

A systematic design study was conducted to determine methods to improve the quality and duration of vacuum conditions in the chamber. A design concept was completed for increasing chamber volume and for allowing for installation of higher capacity vacuum pumps in the future.

Some conceptual planning continued for eventual space flight demonstrations and mission applications. ASPL supported a study by the Revolutionary Aerospace System Concepts team at the Langley Research Center for a large-scale human mission to the moons of Jupiter, envisioned for the fourth decade of this century. The team provided parametric information on a multi-megawatt plasma rocket and consulted on general spacecraft design concepts.

ARES Education and Public Outreach

Jackie Allen
http://ares.jsc.nasa.gov/Education/outreach.htm

Sharing our science with the public is an essential part of ARES programs in Earth and space science. As the small enclave of physical scientists at a NASA engineering and space flight center, our staff is frequently called upon to support presentation and interview requests to the JSC public affairs or education offices. Staff members are active volunteers in the JSC Speaker's Bureau, Distance Learning Network, Texas Aerospace Scholars, NASA Educator Workshops, and National Engineers Week programs; and they support many local science fairs. Our scientists are frequent mentors for university faculty and students in programs sponsored by the NASA education or equal opportunity offices.

Earth Observations E/PO
http://eol.jsc.nasa.gov

Astronaut photography of Earth is extremely popular with students, teachers, and the general public, and this interest is used to leverage interest in science and exploration. ARES provides at least one human space flight image headline per week to "Earth Observatory," NASA's Earth science education flagship website (<<http://earthobservatory.nasa.gov>>). Over 500,000 astronaut photographs of Earth are downloaded each month by educators and the public from the "Gateway to Astronaut Photography of Earth," which has received numerous educational citations (<<http://eol.jsc.nasa.gov>>).

Human Exploration E/PO

ARES exploration staff participates in NASA studies related to future human exploration of the Moon and Mars. They are frequent speakers at public and education venues on the topics of planetary sciences and space farming, resource utilization, early outposts, colonization, and space policy. The intrinsic appeal of humans exploring the solar system is strengthened by our work in the technology of living on other worlds and the science that they might do while there.

Planetary Science E/PO

Our long-term, planetary science education and public outreach programs are funded in association with NASA astromaterials and astrobiology research and Mars exploration. Local partnerships involve ARES scientists and educators working with universities, school districts, and museums. Broader partnerships have become an important vehicle for our education and public outreach. As partners with the Office of Space Science Solar System Exploration Forum, ARES organized and presented *Exploring the Solar System* for Girl Scouts USA trainers in May, 2002. That design was extended to include all the forums in the Office of Space Science in November 2003, and led to an official collaboration between Girl Scouts, USA, and the NASA Office of Space Science. We participated in the development of *Extreme Exploration-Exploring the Solar System 2003-2006*, a collaborative effort to prepare formal and informal educators for the robotic science missions planned over the next three years.

National Girl Scout Trainers

A second partnership has developed with *Science: It's a Girl Thing*, IDEAL Programs, Texas Tech University. This residential summer camp exposes young girls to science and encourages future science course work as they enter secondary school.

ARES is also a major partner in two initiatives that target women and minorities. As co-investigator on an Office of Space Science Minority University Initiative grant to the University of Houston-Downtown, ARES staff trained student ambassadors and Houston teachers in space science activities, and mentored two minority student interns in research at JSC.
Major curriculum projects in 2002-2003 included:

1) Continued development of *Space Rocks Tell Their Secrets* activities and slideshow
2) Development of Mars soil activities for elementary and secondary classrooms
3) Design and delivery of educator workshops for dissemination of astromaterials/astrobiology curriculum

4) Design and delivery of national training program for Girl Scouts using astromaterials/astrobiology curriculum in the informal setting

Our scientist/educator team led activities for the Sun-Earth Day and World Space Congress at the Houston Museum of Natural Science. Our team presented seventeen educator trainings at national and regional National Science Teachers Association conventions, Texas science teachers conventions, and local school districts.

Seven Girl Scout councils invited us to conduct one-day trainings. All of these workshops focused on ARES research using themes of Rocks from Space, Mars, Astrobiology, and Solar System Exploration. Our curriculum products, the primary resources used, are posted on the ARES Education website.

Scaling the Solar System at *Science: It's a Girl Thing*

Exploring Meteorite Mysteries
http://ares.jsc.nasa.gov/Education/Activities/ExpMetMys/ExpmetMys.htm
Exploring the Moon
http://ares.jsc.nasa.gov/Education/activities/ExpMoon/ExpMoon.htm
Fingerprints of Life?
http://ares.jsc.nasa.gov/Education/websites/astrobiologyeducation/index.html
Space Rocks Tell Their Secrets-the slide show only
http://ares.jsc.nasa.gov/Education/spacerocks.htm
Destination: Mars!
http://ares.jsc.nasa.gov/Education/activities/destmars/destmars.htm
Modeling the Solar System
http://ares.jsc.nasa.gov/Education/modelingsolarsystem.pdf

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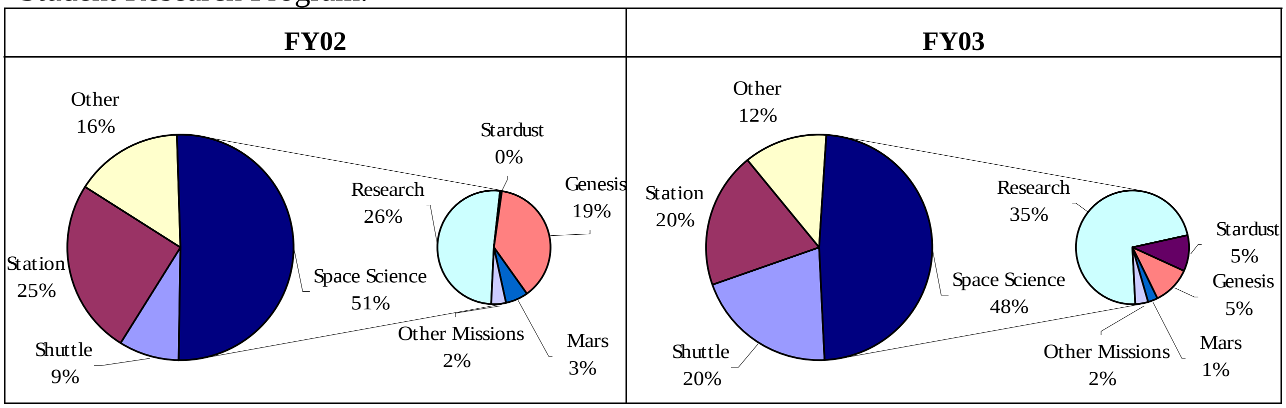
ARES Resources

Finances

ARES receives funding from a variety of different programs. The Shuttle and Station programs provide funding for Orbital Debris, Hypervelocity Impact Technology, Image Science and Analysis, Crew Earth Observations, and ASPL. These activities are performed through Internal Task Agreements (ITAs) with the programs. Space Science continues to contribute approximately 50% of the resources of the organization. All of the Space Science funding comes from peer-reviewed proposals; either individual research projects or flight mission participation. Other program funding includes peer-reviewed research in Earth Science, Technology, Biological and Physical Science, Safety & Mission Assurance, Institutional, and Graduate Student Research Program.



Program	FY02	FY03
Shuttle	*$ 1.400*	*$ 3.262*
Station	*$ 4.075*	*$ 3.122*
Space Science	*$ 8.274*	*$ 7.699*
Other	*$ 2.562*	*$ 1.926*
TOTAL*	**$ 16.311**	**$ 16.009**

** Funding for civil service salaries, benefits, and travel are not included.*

Figure 1: *ARES Finances*

Demographics

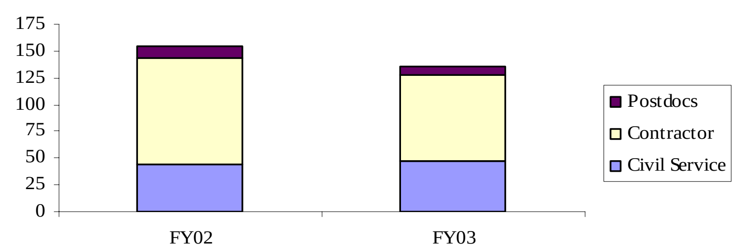


Figure 2: *ARES Personnel*

Personnel within ARES are the key to our success and are composed of NASA civil servants, support contractors, postdocs, students, and interns as well as visiting scientists. All staff are, of course, vital to the success of the organization. The civil service staff has the responsibility for scientific and technical leadership, direction, and vision. To this end, the staff is overwhelmingly technical and highly educated (see Figure 3). We continue to perform exciting research and exceptional analyses due to the initiative, enthusiasm, and ability of the staff to not simply have good ideas, but bring those ideas to fruition.

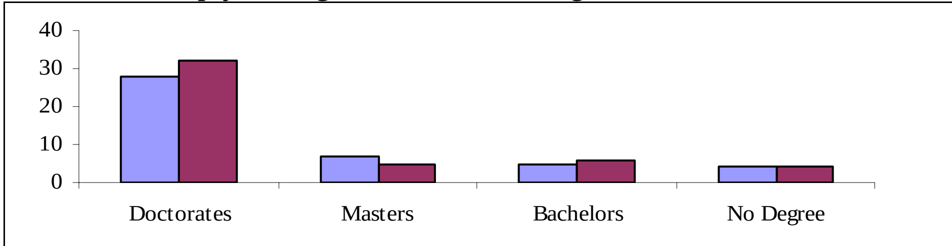


Figure 3: *Education Level of ARES Personnel*

As with many other organizations, ARES is concerned with maintaining a vibrant organization with a mature workforce. As Shown in Figure 4, the age distribution within ARES is bimodal with peaks in the 40s and 60s.

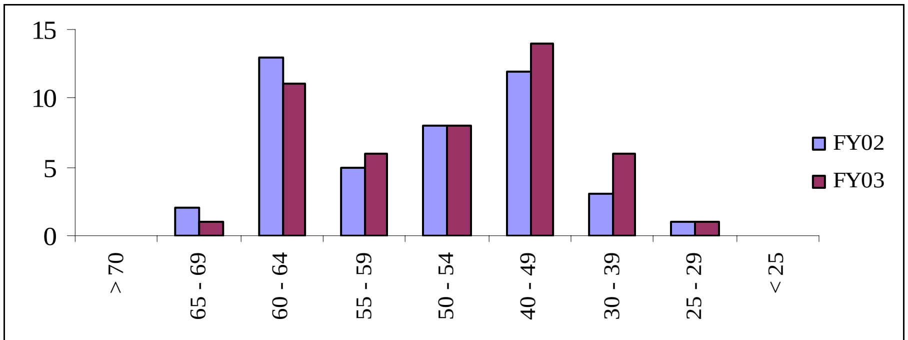


Figure 4: *Age Distribution*

With the addition of new early-career scientists, the workforce eligible for retirement has decreased from 30% in FY02 to 25% in FY03 as shown in Figure 5.

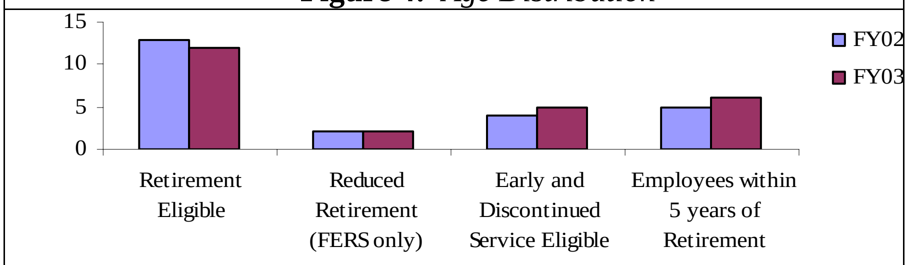


Figure 5: *Retirement Eligibility*

Space

Although the organization faces many challenges, one of the most difficult to address has been inadequate space for research. Many of our laboratories and equipment are dated. We have begun updating equipment and have achieved some new initiatives requiring additional space. We have installed several new instruments: a Triton Thermal Ionization Mass Spectrometer, LV-SEM, FTIR, Laser Raman, created new Laser Analysis and Astrobiology laboratories; and are in the process of installing a curatorial lab for the Stardust mission, Plasma Deposition lab, Complete Angle Light Scattering lab, and a Multi-Anvil Experimental Petrology lab. All of these additions must be accommodated in our current building. As a result, there are significant, ongoing challenges that we hope to resolve in the next two years.

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Marilyn M. Lindstrom, Ph.D.	Scientist*	Education
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Bobby L. Simpson	Engineer	Hyper V Impact
Dimitris M. Xirouchakis	TSU postdoc	Astromaterials

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ARES Award Recipients 2002–2003

External Honor Awards

Innovation Award for Space Science and Technology – Discover Magazine
Franklin Chang-Diaz (2003)

Nier Prize for Meteorites
Scott Messenger, Ph.D.

NASA Honor Awards

Exceptional Service Medal
Eileen K. Stansbery (2003)

NASA Distinguished Service Medal
Franklin Chang Díaz, Ph.D.

Group Achievement Award
Remote Lunar Sample Storage Facility Team (2003)
ER2 Flight Group

NASA Silver Snoopy Award
Donn Liddle
J. C. Liou, Ph.D.

NASA Space Act Award
Justin Wilkinson, Ph.D.
D. C. Golden, Ph.D.
Rick Socki
Vern Lauer, Ph.D.
Craig Schwandt, Ph.D.

Space Flight Awareness Award
Fadi Riman

NASA Software Awards
Testing Management System (TMS)
- Freeman Bertrand
- Jim Hyde
- Jay Laughman
- Dana Lear

Frankel Lyons

BUMPER-II version 1.92b
Ron Bernhard
Freeman Bertrand
Alan Davis
Bill Davidson
Jim Hyde
Jay Laughman
Dana Lear
Frankel Lyons
Tom Prior

Shuttle Payload Bay Door Radiator Damage Web Application
Ron Bernhard
Jim Hyde
Dana Lear

NASA Johnson Space Center Honor Awards

Space Act Award
Eric L. Christiansen, Ph.D. – Tech Brief 2 and Patent Applications
Justin H. Kerr – 2 Patent Applications

Space and Life Sciences Directorate Awards

Scientific Sustained Superior Achievement
Gary Lofgren, Ph.D.

Special Scientific Achievement
Everett K. Gibson, Ph.D.
Mark Matney, Ph.D.
Hayabasu NASA Science Team
Lunar Sample Processing Team
Mars Exploration Rover Team
Astrobiology Laboratory Team
Astrobiology Institute Proposal Team

Special Space Flight Achievement
Image Analysis Team

Special Professional Achievement

Karen McNamara, Ph.D. (2003)
James Holder

Professional Sustained Award – Individual

Loan Le
Jer Chyi Liou, Ph.D.

Professional Special Award – Individual

Eleanor Cizek

Excellence Team Award

Mary Sue Bell
Donna Castillo
GeorgAnn Robinson
Craig Schwandt, Ph.D.
Tom See
Lisa Vidonic
Jerry Wagstaff

Scientific Sustained Team Award

Brett McRay
Mike Trenchard
Justin Wilkinson, Ph.D.
Kim Willis

Scientific Special Team Award

Early Scientific Results from the ISS
Cynthia Evans, Ph.D.
Julie A. Robinson, Ph.D.

Remote Lunar Sample Storage Facility Team
Ron Bastien
Terrie Bevill
Donna Castillo
Jimmy Holder
Andrea Mosie
Terry Parker
J. R. Sanchez
Carol Schwarz
Lisa Vidonic
Jack Warren

Genesis Facility Clean Room Floor Replacement Team
Judy Allton
Ron Bastien
Donna Castillo
Ricky Garrett
Jerome Hittle
Jimmy Holder
Helen Mays
Terry Parker
Norma Ramirez
Craig Schwandt, Ph.D.
Thomas H. See
Lisa Vidonic
Jack Warren

<u>Space Flight Special Team Award</u>
David R. Bretz
Kevin L. Crosby
Donn A. Liddle
Erica H. Miles
Eric A. Nielsen
Edward R. Oshel
Robert Scharf

<u>Going the Extra Mile (GEM) Award</u>
John Christiansen, Ph.D.
David Bretz
Eric Nielsen
James Holder

<u>Summer Co-op Award</u>
Emily Leestma

Lockheed Martin Science Engineering Analysis and Test (SEAT) Awards

<u>Lockheed Martin Employee of the Month</u>
James Hyde

<u>Lockheed Martin Top Flight Awards</u>
STS-107 Photo/TV Analysis Team
Joe Caruana
Kevin Crosby
Jon Disler

Cynthia Evans, Ph.D.
James Heydorn
Kandy Jarvis
Amanda Johnson
Donn Liddle
Mark Matney, Ph.D.
Brett McRay
Erica Miles
Teresa Morris
Julie Robinson, Ph.D.
Glynda Robbins
Prem Saganti, Ph.D.
Robert Scharf
Mike Snyder
Tracy Thumm
Leslie Upchurch
Justin Wilkinson, Ph.D.
Kim Willis

Lockheed Martin Educational Award

Quanette Lee Juarez
Dana Lear

Lockheed Martin Lightning Award

Ron Bastien
Donna Castillo
Kevin Crosby

Lockheed Martin Safety Award for Excellence (SAFE)

Freeman Bertrand
Chuck Landrum
Jay Laughman
Terry Parker
William (Bill) Davidson

Lockheed Martin Special Recognition Award

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Simon Clemett, Ph.D.
Cynthia A. Evans, Ph.D.
Daniel Garrison
Mark Matney, Ph.D.
Thomas See
Mike Snyder

Lockheed Martin Commendation Award

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Barry Schroder
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Alan Spraggins
Tracy Thumm
Leslie Upchurch
Justin Wilkinson, Ph.D.

Earth Observations Mission Operations Team
Brett McRay
Mike Trenchard
Justin Wilkinson, Ph.D.
Kim Willis

Lockheed Martin Team Award

Orbital Debris Reentry Modeling Group
William Rochelle
John Opiela

Lockheed Martin Caught in the Act (CIA) Award

Ron Bernhard
Charles (Chuck) Landrum

<u>Lockheed Martin Police Department Commendation Award</u>

David Bretz
Eric Nielsen